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PHYSIOLOGICAL STUDIES OF THE EFFECT OF ARSENICALS ON THE RESPIRATORY METABOLISM OF INSECTS [1]

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INTRODUCTION

In previous investigations (*7*) [3] it was established that during the embryonic development and metamorphosis of insects, the average oxygen consumption and carbon dioxide output, when plotted against time, produced graphs which in general indicated an increase in the gaseous exchange from a minimum during early development to a maximum as developmental processes terminated. The substance chiefly utilized as energy for an upbuilding of the organism in the metabolic process was found to be reserve fat. It was also shown that in consequence of histolysis the average results of the respiratory gas exchange when plotted as above produced graphs of a reverse order, indicating a maximum gaseous exchange at the beginning of histolysis and a minimum exchange as the histolytic process terminated. Recently the type of metabolic activity that functions during starvation and hibernation of insects has also been indicated (*8*). It appeared, therefore, of considerable interest in a study of arsenicals to observe their action upon respiratory metabolism.

If the information from such a study substantiates a relationship between susceptibility and physiological or metabolic activity, it may be possible to distinguish a degree of susceptibility to arsenical poisoning of tissues and organs, and to elucidate the factors involved in acquired tolerance of organisms to low concentrations of poison.

In the literature, references to the influence of arsenicals upon the respiratory metabolism of insects appear to be entirely lacking. Shafer (*11*, *12*) has indicated the inhibiting influences which substances like gasoline, kerosene, carbon disulphide, hydrocyanic-acid gas, sodium fluoride, and others exert upon respiration and upon oxidases, catalases, and reductases. He found that the respiratory activity of treated insects increased until they became deeply affected, after which it was depressed. These gases also caused the value of the respiratory quotient to rise above that of normal animals. The conclusion derived was that these vapors depress the O_2 absorption more than they do the CO_2 excretion. Child (*4*), Hyman (*9*), and others have verified the inhibiting effect of potassium cyanide (KCN) upon the gaseous exchange in Planaria. Cunze (*6*) found a

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[3] Reference is made by number (italic) to "Literature cited," p. 1007.

reduction of the gaseous exchange as a result of the injection of arsenic trioxide in rabbits.

In the present investigations an attempt has been made to determine the influence that arsenical compounds and their component oxides and arsenic contents have upon the respiratory metabolism of insects.

MATERIAL AND METHODS

The material employed in these investigations consisted of the adult potato beetle, *Leptinotarsa decemlineata* Say, the garden wireworm, *Pheletes agonus* Say, and third-stage larvae of the Japanese beetle, *Popillia japonica* Newman.

Measurements of respiratory metabolism were made with a Krogh's manometer as modified by Bodine and Orr (*1*). Further minor modifications made by the writer consisted in widening the diameter of the shank to accommodate wider-mouthed respiratory chambers, in fusing a glass hook to the bottom of the shank from which the insect was suspended, and in increasing the length of the capillary tubes. This last modification enabled determinations to be made with comparatively large insects.

It is essential in respiratory investigations that basal metabolism be determined; hence the voluntary movements of insects under experimentation were controlled by confining the insects in cotton gauze and tying them to eliminate body movements or muscle tonus. Wireworms, however, persistently worked themselves loose from gauze, and it was found convenient to use instead pieces of heavy unbleached muslin, which did not interfere with their normal respiration. The insects with body movements thus controlled were suspended from the small glass hook in the respiratory chamber of the manometer. They could be left in the chamber for 2 to 10 hours as the nature of the experiment demanded. Constant temperatures were maintained by the use of a water bath in which the respiratory chambers of the manometer were immersed.

The procedure in all investigations was first to determine the normal rates of metabolism of an insect and afterwards to feed it poisoned foliage, or to place a known quantity of an arsenical solution on the mouth parts to be absorbed by the insect, or to inject in the oral cavity the quantity of solution to be tested. In some experiments the insects were left on poisoned foliage for only a few hours and in others they were left from 10 to 16 hours before their metabolic rates were again determined.

Uniform suspensoid solutions of lead arsenate, calcium arsenate, manganese arsenate, and ferric arsenate were made by using 0.145 gm. of the arsenical per 100 cubic centimeters of water (*5*). The calculations were based upon the average arsenic oxide content (32 per cent) present in the arsenical, such proportions being the equivalent of those used in field control of insects, namely, 2 pounds of the arsenical to 50 gallons of water. The prepared solutions were sprayed on potato foliage by means of a fine syringe and the foliage was then fed to insects. For the purpose of uniformity only those insects were selected for metabolism determinations that indicated a consumption of poisoned foliage equivalent (approximately) to that consumed by insects that were feeding on foliage sprayed with a different arsenical. The results obtained from such experiments gave the effect produced by the arsenical compound on respiratory metabolism.

In determining the effect of the oxide component of the arsenical compound upon respiration, neutral suspensoid solutions (0.001 gm. per cubic centimeter of water) of lead oxide, calcium oxide, manganese oxide, and ferric oxide were prepared and fed to insects by means of a small graduated pipette having the tip drawn out into a fine capillary,[4] similar in principle to the micro burette described by Campbell (*2*). A definite quantity of liquid (0.01 c. c.) was used in each case and was placed on the mouth parts of the insect in minute droplets, the liquid flowing from the pipette by gravity or slight mouth pressure at a sufficiently slow rate to be absorbed by the insect.

For the purpose of determining the effect of the arsenical alone upon respiratory metabolism, neutral solutions of arsenious acid and of arsenic acid were fed to the insects by means of the graduated pipette already mentioned and also by means of a small hypodermic syringe, a definite quantity being injected in the oral cavity of the insect.

Realgar (As_2O_2) and manganese arsenate were utilized chiefly because of their color property. It was thought that as portions of the poison upon which the insects fed became absorbed and distributed in the body, their color (realgar is red, manganese arsenate is grayish brown) might prove of some aid in distinguishing their location in tissues and organs, but subsequent histological investigations of insects fed on these agents did not substantiate this view.

EXPERIMENTAL DATA

For the sake of brevity and clearness the data of the experiments have been averaged and summarized in the accompanying tables and figures. For the methods used in calculating the results the reader is referred to the article by Krogh (*10*).

TABLE 1.—*Average respiratory gas exchange of female potato beetles to which arsenicals were fed for 16 hours*

Group No.[a]	Kind of feeding	O_2 intake	Probable error ±	CO_2 output	Probable error ±	$\frac{CO_2}{O_2}$	Probable error ±	Per cent depression[b]	
								O_2	CO_2
		C. c.		*C. c.*					
L_1	Normal	64.00	1.85	37.15	5.03	0.580	0.029		
	Lead arsenate	58.59	7.01	42.60	5.74	.727	.025	8	[c]+12
L_2	Normal	97.48	4.92	61.29	7.20	.628	.013		
	Lead arsenate	30.91	8.34	15.62	2.75	.505	.029	68	74
L_3	Normal	46.40	2.64	26.10	3.45	.562	.024		
	Lead arsenate	50.50	3.62	37.00	2.79	.732	.019	+8	+29
L_4	Normal	56.80	2.14	44.70	2.57	.787	.015		
	Lead arsenate	55.70	5.40	41.40	2.29	.743	.037	2	7
L_5	Starving	31.70	1.90	15.60	2.12	.492	.017		
	Lead arsenate	24.10	2.70	10.70	3.74	.444	.033	24	31
L_6	Normal	110.68	8.60	87.15	5.66	.787	.013		
	Manganese arsenate	68.23	9.36	40.80	7.40	.597	.033	38	54
L_7	Normal	113.42	2.15	83.28	2.58	.734	.024		
	Realgar	124.90	2.96	79.65	2.20	.637	.017	+9	4
L_8	Normal	105.66	2.50	83.49	15.00	.790	.027		
	Calcium arsenate	66.30	6.70	47.80	6.80	.721	.025	37	42
L_9	Normal	136.45	4.50	99.20	3.80	.727	.019		
	Ferric arsenate	114.15	3.20	81.70	2.70	.717	.021	16	17

[4] The pipette used by the writer was made of glass tubing 10 cm. long and 2 mm. inside diameter, the tip drawn into a fine capillary. A strip of millimeter paper was pasted the length of the tube and the pipette was calibrated with mercury. The liquid flowed by gravity, or by mouth pressure when a compensating tube was connected by rubber tubing to the capillary.

[a] L_1, L_2, L_4, old beetles; L_2, L_8 to L_9, young beetles; L_5, starving beetles.
[b] By "depression" is meant the deviation from normal metabolism attributable to the poison.
[c] Plus sign before figure indicates an increase in percentage.

TABLE 2.—*Average respiratory gas exchange of male potato beetles to which arsenicals were fed for 16 hours*

Group No.[a]	Kind of feeding	O_2 intake	Probable error ±	CO_2 output	Probable error ±	$\frac{CO_2}{O_2}$	Probable error ±	Per cent depression[b]	
								O_2	CO_2
		C. c.		*C. c.*					
L_1	Normal	65.52	3.11	41.99	7.20	0.641	0.043		
	Lead arsenate	63.16	1.19	44.80	5.10	.709	.046	3	[c]+6
L_2	Normal	116.80	1.35	78.09	1.56	.668	.023		
	Lead arsenate	33.94	1.89	31.14	3.54	.917	.019	71	60
L_3	Normal	66.60	2.76	47.70	2.16	.723	.021		
	Lead arsenate	56.80	1.54	38.90	3.42	.685	.025	13	18
L_4	Starving	61.55	2.86	40.90	3.01	.664	.026		
	Lead arsenate	37.02	3.21	22.10	1.92	.596	.038	40	46
L_5	Normal	107.60	2.55	77.05	4.20	.716	.034		
	Manganese arsenate	61.00	3.20	41.20	2.15	.675	.061	43	46
L_6	Normal	148.50	2.67	115.00	3.50	.774	.024		
	Realgar	160.10	2.21	132.00	2.30	.824	.016	+7	+12
L_7	Normal	71.15	3.45	69.13	2.43	.971	.025		
	Calcium arsenate	18.10	3.20	18.10	1.76	1.000	.011	74	73
L_8	Normal	92.60	2.10	74.10	1.87	.800	.017		
	Ferric arsenate	50.80	3.40	33.60	2.37	.661	.019	45	55

[a] L_1, L_3, old beetles; L_2, L_5 to L_8, young beetles; L_4, starving beetles.
[b] By "depression" is meant the deviation from normal metabolism attributable to the poison.
[c] Plus sign before figure indicates an increase in percentage.

TABLE 3.—*Percentage deviation from normal of the gas exchange of first-generation potato beetles fed different arsenicals*

Poison used	Sex of beetles	O_2 intake	CO_2 output	$\frac{CO_2}{O_2}$
Lead arsenate	Female	−68	−74	−19
Do	Male	−71	−60	+18
Calcium arsenate	Female	−37	−42	−8
Do	Male	−74	−73	+3
Manganese arsenate	Female	−38	−54	−24
Do	Male	−43	−46	−5
Ferric arsenate	Female	−16	−17	−1
Do	Male	−45	−55	−17
Realgar	Female	+9	+4	−13
Do	Male	+7	+12	+6

Tables 1 to 3 indicate the average oxygen consumption, carbon dioxide production, and respiratory quotient [5] resulting from normal feeding, and the rates after a certain period of feeding on sprayed foliage. The deviation from normal metabolism attributable directly to poisoned food has been calculated in terms of percentage and placed in a separate column ("Per cent depression"). These figures give a clear conception of the effect of the poison upon the insects under experimentation.

RESULTS WITH LEAD ARSENATE

Experimentally, the oxygen consumption and the carbon dioxide output of first-generation beetles (young insects) after feeding on poisoned foliage were persistently and profoundly lowered (Tables 1 to 3). The reduction varied with different individuals; the average decline for young females (Table 1) was 68 and 74 per cent, and for

[5] By "respiratory quotient" is meant the ratio of the CO_2 output to the O_2 intake, and is usually designated as $\frac{CO_2}{O_2}$.

young males (Table 2) 71 and 60 per cent. Old beetles after feeding on sprayed foliage gave different results. In females the average oxygen intake of three groups (L_1, L_3, and L_4) as compared to normal rates was practically unaffected; the CO_2 output, on the other hand, rose 17 per cent. In males the oxygen consumption decreased 8 per cent and the CO_2 output decreased 12 per cent. A marked elevation in the respiratory quotient of young males (27 per cent) was noted in these tests, whereas in young females a decline of 19 per cent occurred. No significant rise in the quotient of old males took place (4 per cent); old females, however, exhibited an increase of 19 per cent (fig. 1).

The effect that starvation may have on susceptibility to arsenical poisoning was also investigated. Male beetles, starved for a week

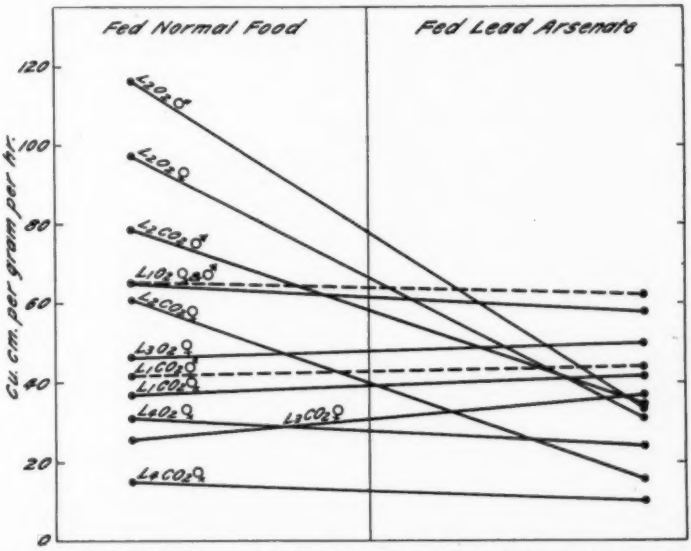

FIG. 1.—Normal rates of respiratory metabolism of four groups of potato beetles and effect produced on metabolism by the consumption of lead arsenate. L_1 and L_2, old beetles; L_3, young beetles; L_4, starving beetles. Note the intense inhibiting effect of the poison on young as compared to old beetles

and afterwards placed on sprayed foliage, registered an intense lowering of the oxygen intake and CO_2 output, amounting to 40 and 46 per cent, respectively. In females the reduction amounted to 24 and 31 per cent. The theory that starvation may lead to physiological youngness would seem to be upheld by the susceptibility of starved beetles to arsenical poisoning, a susceptibility comparable to that of young beetles, as discussed above.

When potato beetles survived for three days the effects of feeding on sprayed foliage, it was possible to note the influence which such feeding produced on metabolism. From Figure 6, D, it will be observed that a gradual lowering of the oxygen intake occurred during the entire period of the experiment, whereas a diminution of the CO_2 output took place during the first day, followed by a slight rise on

the second day, a more decided reduction on the third day, and finally by the death of the individual. In the same figure the curve for the respiratory quotient is gradually elevated during the first two days, indicating that the substances catabolized were entirely different from those in normal metabolism. From the high quotient (0.8) and the dissolution of muscle tissues noted frequently in dissecting poisoned insects before death, it is surmised that muscle tissue destruction or protein metabolism very largely took place.

The average loss in weight sustained by 37 individuals which fed on foliage sprayed with lead arsenate amounted to 13 per cent of their total weight. Contrary to expectation, this reduction was not so great as that sustained by beetles which were fed foliage sprayed with other arsenicals, as will be discussed later. In other experiments grains of corn soaked in arsenic acid solutions (0.0115 gm. per cubic centimeter) were placed with wireworms, and after the wireworms had fed on the poisoned grain, measurements were made of the respiratory exchange. The oxygen intake and the CO_2 output were found to be reduced 24 and 18 per cent, respectively (Table 4). An increase of 6 per cent in the quotient was registered, but this is not considered significant.

TABLE 4.—*Average respiratory gas exchange of wireworms which were fed arsenicals*

Kind of feeding	O_2 intake	Probable error±	CO_2 output	Probable error±	$\frac{CO_2}{O_2}$	Probable error±	Per cent depression	
							O_2	CO_2
	C. c.		*C. c.*					
Normal	121.20	4.10	86.50	3.20	0.714	0.092		
Lead arsenate	91.70	2.90	70.10	4.80	.764	.084	24	18
Normal	91.30	3.10	77.50	2.80	.848	.047		
Calcium arsenate	76.10	3.80	71.20	1.90	.936	.036	16	8

RESULTS WITH CALCIUM ARSENATE

First-generation females after feeding on foliage sprayed with calcium arsenate registered a lowering in oxygen intake and CO_2 output of 37 and 42 per cent, respectively (Table 1); first-generation males showed a reduction of 74 per cent oxygen intake and 73 per cent CO_2 output (Table 2). Figure 2 gives a graphic representation of the results based on an average of 21 individuals. The influence of calcium arsenate on metabolism when continued for a period of two days is shown in Figure 6, A. It should be explained that the gradual elevation of the oxygen intake as shown in this figure is attributable to the age of the insects and is comparable to the curve shown in Figure 1 for old beetles. The increase in CO_2 output occurs only on the first day and is followed by a marked depression on the second day. The quotient, however, continues to ascend for the entire period of the experiment, presumably indicating that the substances catabolized are similar in nature to those discussed under lead arsenate and are entirely different from those in normal metabolism. The average loss in weight sustained by 18 insects amounted to 16 per cent of their total weight.

Tests similar to those with lead arsenate were conducted with calcium arsenate on wireworms (Table 4). A decrease in the oxygen

consumption and CO_2 output of 16 and 8 per cent, respectively, is here shown. A significant rise in the quotient (9 per cent) took place.

RESULTS WITH MANGANESE ARSENATE

The feeding of foliage sprayed with manganese arsenate likewise profoundly decreased the oxygen intake and CO_2 output of both sexes, as shown in Figure 3. The depression of the gaseous exchange in females averaged 38 and 54 per cent, respectively (Table 1), in males 43 and 46 per cent (Table 2), and a decline in the quotient amounted in females to 24 per cent and in males to 5 per cent.

Figure 6, B, shows the results of experiments in which manganese arsenate affected potato beetles for a period of four days. It will

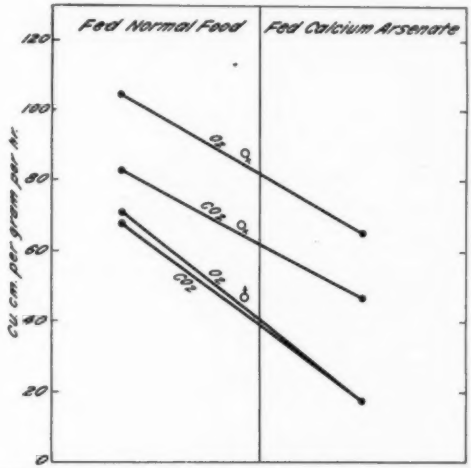

FIG. 2.—Normal rates of respiratory metabolism of first-generation male and female potato beetles, and effect produced on metabolism by the consumption of calcium arsenate

be noted from the curves in this figure that a depression of the gaseous exchange occurred during the first two days, followed by an increase on the third day. A considerable decline in the CO_2 output took place just before the death of the insects. The curve for the respiratory quotient parallels for most of its length the curve indicated for CO_2 production. The average loss in weight sustained by 28 beetles, attributable to arsenical feeding, amounted to 26 per cent. The curves in Figure 6, F, which are comparable in many respects to those for the adults (fig. 6, B), represent the reactions of larvae to similar tests.

RESULTS WITH FERRIC ARSENATE

With ferric arsenate the oxygen consumption and CO_2 production of females decreased only 16 and 17 per cent, respectively, but with males the depression was 45 and 55 per cent (Tables 1, 2, and 3 and fig. 4). The respiratory quotient of females remained practically normal, whereas in males it decreased 17 per cent. It is very

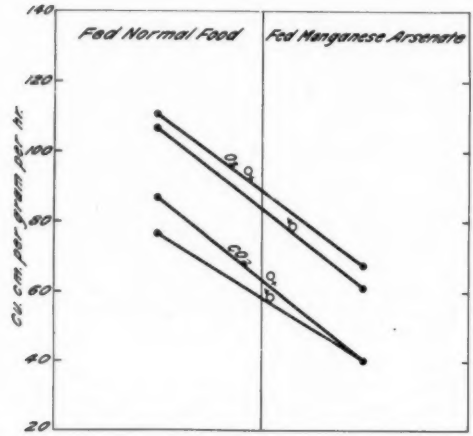

FIG. 3.—Normal rates of metabolism of potato beetles and effect of manganese arsenate on the oxygen intake and carbon dioxide output

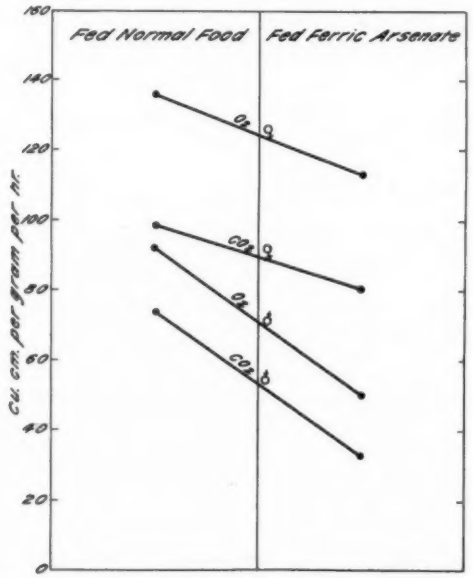

FIG. 4.—Normal rates of metabolism and effect of ferric arsenate on the oxygen intake and carbon dioxide output of potato beetles

likely that the divergence in the normal condition of the sexes as shown in Tables 1 and 2 was a primary factor in the reactions of these insects to ferric arsenate.

RESULTS WITH REALGAR (ARSENIC DISULPHIDE)

Realgar produced entirely different results from the arsenicals noted above. Since both the oxygen intake and CO_2 output of the beetles were increased during the first day, it would seem that realgar had a stimulating effect on metabolism. The average increase in the oxygen consumption of females was 9 per cent, in males 7 per cent. A decline of 13 per cent in the quotient in females occurred and a rise of 6 per cent in males (Tables 1 to 3 and fig. 5). Further proof of the stimulating effect of realgar is shown by the average increase in weight of 15 individuals, amounting to 0.9 per cent. The influence of realgar on metabolism when continued for a period of three days (fig. 6, E) shows that the respiratory exchange decreased profoundly during the last day.

The toxicity of an arsenical usually depends upon its solubility, the facility with which it can be absorbed by protoplasm, and the rate at which it can be excreted. From unpublished data on the solubility of arsenicals in the digestive tract of insects, it appears that the first stimulating effect of realgar on the respiratory exchange is attributable to its slight solubility and absorption by the protoplasm, and to its comparatively rapid rate of excretion. Further ingestion of realgar, however, finally brings about a cumulative effect and causes a depression of the gaseous exchange, as shown in Figure 6, E. This behavior of realgar may hold true also of any other arsenical which is ingested at first in very small quantities, or which like realgar has a comparatively low solubility and is rapidly excreted from the digestive system.

TABLE 5.—*Average respiratory gas exchange of potato beetles fed the oxide component of arsenical compounds*

Kind of feeding	O_2 intake	Probable error±	CO_2 output	Probable error±	$\frac{CO_2}{O_2}$	Probable error±	Per cent depression	
							O_2	CO_2
	Cu.mm.		*Cu.mm.*					
Normal	390	3.21	305	2.65	0.782	0.032		
Lead oxide (with pipette)	310	2.15	246	1.88	.793	.025	20	19
Normal	357	1.72	217	1.87	.607	.037		
Calcium oxide (with pipette)	337	1.79	206	2.16	.611	.042	5	5
Normal	320	3.81	230	2.11	.718	.063		
Manganese oxide (with pipette)	212	1.86	189	3.25	.891	.039	34	17
Normal	296	3.26	193	2.34	.652	.024		
Ferric oxide	235	2.46	147	1.83	.625	.014	20	23

RESULTS WITH THE OXIDE COMPONENT OF ARSENICALS

The results of the tests with the oxide component of arsenical compounds are shown in Table 5 and in Figure 7. From Figure 7 it is readily noted that in every case a depression of the gaseous exchange occurred. With lead oxide (PbO) the depression amounted to 20 per cent in the oxygen consumption and 19 per cent in the CO_2 output; with manganese oxide (MnO) 34 and 17 per cent; with ferric oxide (Fe_2O_3) 20 and 23 per cent; with calcium oxide

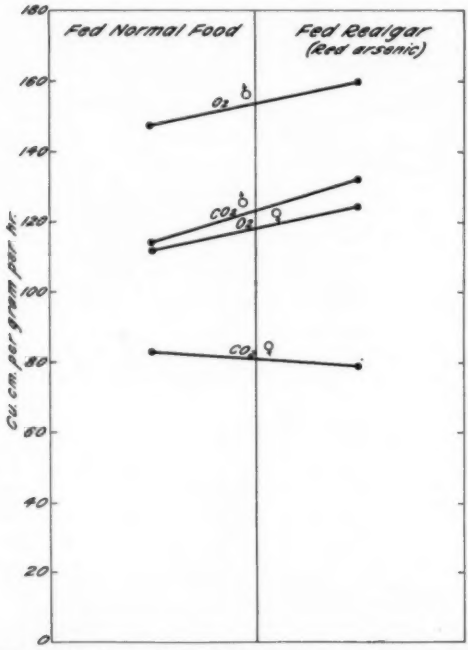

FIG. 5.—Normal rates of metabolism and effect of realgar on the oxygen intake and carbon dioxide output of potato beetles. Note the stimulating effect of feeding for one day and compare with Figure 6, E, where the beetles fed for 3 days

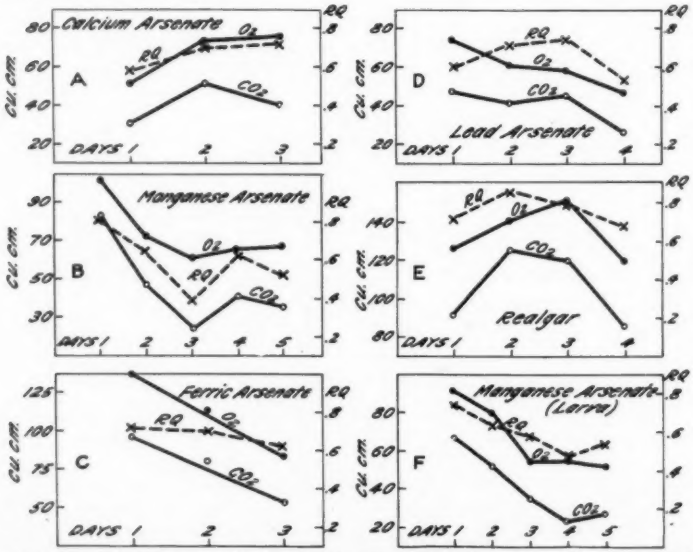

FIG. 6.—Effect on the metabolism of potato-beetle larvae and adults when feeding with various arsenicals was continued for several days

(CaO) an insignificant depression of only 5 per cent in both the oxygen consumption and the CO_2 production. It is quite evident from these results that the oxides possess some insecticidal qualities.

A slight increase in the respiratory quotient, especially with manganese and lead oxides, was obtained as a result of these tests.

RESULTS WITH ARSENIOUS ACID (As_2O_3), ARSENIC ACID (As_2O_5),[6] SODIUM ARSENITE (Na_2HAsO_3), AND SODIUM ARSENATE ($Na_2AsO_4.12H_2O$)

The effect of arsenical compounds and of the oxide components on the respiratory metabolism of insects having been determined, a series of experiments with various dilutions of arsenious and arsenic acid were made to ascertain the effect that arsenic alone plays in depressing the gaseous exchange. After a large number of preliminary trials with dilutions of different concentrations, a neutral dilution of arsenious and arsenic acid was obtained that depressed the oxygen consumption to an equal degree with either substance. The concentration of arsenious acid per cubic centimeter was 0.00495 gm., and the concentration of arsenic acid per cubic centimeter was 0.0115 gm. These dilutions of arsenic were fed to the insects by means of a small graduated pipette, as previously described, which could deliver, by means of small drops of fluid flowing by gravity or slight mouth pressure, exactly 0.01 c. c. of solution. Other tests were included in which a small hypodermic syringe was used, and a definite quantity, that is, 0.01 c. c., was injected into the oral cavity. The objectionable feature of the syringe is that the forcing of the entire amount of liquid into the oral cavity causes the insects, in some instances, to regurgitate some of the injected fluid. Nevertheless, the results as a whole compare favorably with those obtained by means of the graduated pipette. The results of these experiments are averaged and summarized in Table 6. In Figure 8 the curves were drawn to show the effect of sodium arsenite and arsenate and arsenious and arsenic acids upon the respiratory metabolism of *Pheletes agonus*, *Leptinotarsa decemlineata*, and *Popillia japonica*. In the graphs of this figure the depression of the oxygen consumption is represented at hour intervals for the first 2 to 6 hours, and the effect on the oxygen intake 16 to 18 hours later is also shown. Utilizing the oxygen depression as a basis for judging the relative toxicity of the solutions on different species of insects, the graphs strikingly reveal the fact that the depression is more intense during the first few hours after the poison is consumed than at a later period. After this initial period of depression the lowering of the oxygen consumption continues gradually until a maximum is reached. This maximum of depression is utilized as a basis for comparing the relative toxicity of arsenious and arsenic acid.

[6] Anhydride arsenious and arsenic acids dissolved in water were used in these experiments, and for the sake of brevity and clearness are designated in the discussion as As_2O_3 and As_2O_5, respectively.

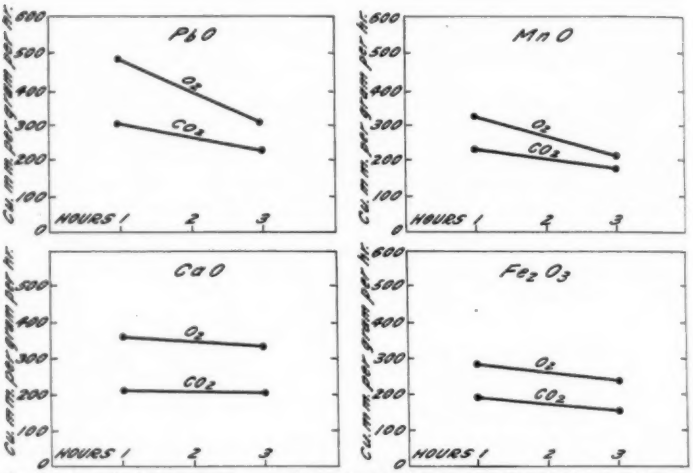

FIG. 7.—Normal rates of oxygen consumption and carbon dioxide output and the effect of 0.01 mgm. doses of lead oxide (PbO), calcium oxide (CaO), manganese oxide (MnO), and ferric oxide (Fe_2O_3) on the respiratory metabolism of potato beetles

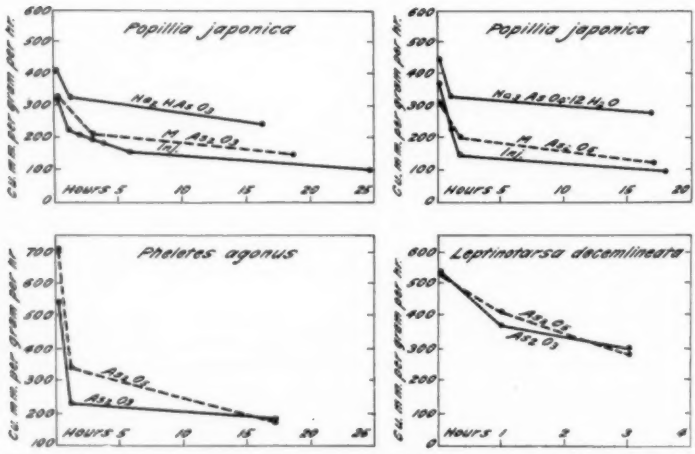

FIG. 8.—Effect of arsenious acid (As_2O_3), arsenic acid (As_2O_5), sodium arsenite (Na_2HAsO_3), and sodium arsenate ($Na_2AsO_4.12H_2O$) on *Leptinotarsa decemlineata*, *Phaletes agonus*, and *Popillia japonica*. The dotted line *M* represents feeding with pipette, the solid line *Inj.*, feeding by injection in the oral cavity. This figure shows the oxygen inhibition at hour intervals. Note the intense depression which occurs during the first few hours as compared to that which occurs during the remaining period of the experiment

Since the concentrations of arsenious acid used were 0.00495 gm. per cubic centimeter, and of arsenic acid, 0.0115 gm. per cubic centimeter, the results show that the former was 57 per cent more toxic than the latter. Similarly, the curves representing the oxygen depression caused by sodium arsenite and sodium arsenate are practically identical in nature and reach the same level of depression (fig. 8). The concentration of sodium arsenite used was 0.0017 gm. per cubic centimeter, and the concentration of sodium arsenate was 0.00424 gm. per cubic centimeter. By calculating the relative toxicity of the two substances, it is found that the former is 59 per cent more toxic than the latter. Campbell (*3*) found that the arsenite was more toxic than the arsenate to the tent caterpillar, *Malacosoma americana* Fab.

A significant increase in the respiratory quotient was obtained as a result of these tests, as is shown in Table 6.

TABLE 6.—*Average respiratory gas exchange of insects fed dilutions of arsenious acid* (As_2O_3), *arsenic acid* (As_2O_5), *sodium arsenite* (Na_2HAsO_3), *and sodium arsenate* ($Na_3AsO_4.12H_2O$)

Insect used	Kind of feeding	O_2 intake	Probable error ±	CO_2 output	Probable error ±	$\frac{CO_2}{O_2}$	Probable error ±	Per cent depression	
								O_2	CO_2
		Cu.mm.		*Cu.mm.*					
P. japonica	Normal	415	2.19	244	3.27	0.587	0.026		
Do	Na_2HAsO_3 (injected)	250	3.01	229	1.77	.916	.033	40	6
Do	Normal	446	1.83	185	1.59	.414	.018		
Do	$Na_3AsO_4.12H_2O$ (injected).	279	2.78	114	2.01	.408	.053	37	38
Do	Normal	322	4.52	221	3.72	.686	.068		
Do	As_2O_3 (injected)	150	3.06	141	1.57	.940	.042	53	36
Do	Normal	320	2.75	198	3.55	.618	.069		
Do	As_2O_3 (pipette)	115	2.81	97	2.04	.843	.042	64	51
Do	Normal	376	1.92	143	2.73	.380	.016		
Do	As_2O_3 (injected)	99	2.66	86	1.87	.868	.062	73	40
Do	Normal	315	3.66	253	3.42	.803	.063		
Do	As_2O_3 (pipette)	120	1.91	117	2.68	.975	.033	61	54
P. agonus	Normal	543	1.79	276	2.43	.508	.045		
Do	As_2O_3 (injected)	163	3.21	127	1.58	.779	.097	70	53
Do	Normal	708	2.07	287	2.34	.405	.041		
Do	As_2O_3 (injected)	171	1.89	123	3.42	.719	.044	75	57
L. decemlineata	Normal	550	1.76	321	4.13	.583	.035		
Do	As_2O_3 (pipette)	301	1.71	202	1.93	.671	.055	45	37
Do	Normal	546	2.36	341	1.59	.624	.027		
Do	As_2O_3 (pipette)	287	1.83	214	2.76	.745	.024	47	37

DISCUSSION

The evidence from a study of the data presented points to the general fact that arsenicals exert an inhibiting effect on the respiratory metabolism of insects. The significance of this inhibition lies in the fact that with young insects the metabolic activity is extremely more marked, and the reduction, therefore, more intense than with older ones. This would seem to indicate that the physiological activity of the living protoplasm is of prime importance in susceptibility to arsenical poisoning, since differences in susceptibility of groups of insects (young and old) correspond to differences in physiological age. In a previous investigation (*8*) it was pointed out that with the potato beetle the oxygen consumption and the carbon dioxide output decreased with advancing age and that a corresponding decline in the rate of oxidation through the inhibition of the enzymes

(oxidases and catalases) took place. Similarly, it would seem, a reduced metabolic activity as a result of arsenical feeding may be traced to the inactivation of oxidizing enzymes, which in some way prevents oxidative reactions. Shafer (*12*) called attention to the fact that certain volatile substances, such as gasoline and carbon disulphide, affect the oxidative and catalase activity of *Passalus cornutus* Fab. Voegtlin (*13*) suggested that the action of arsenic upon protoplasm is essentially due to an interference with the normal functioning of glutathione in the oxidation-reduction phenomena of tissues. The presence of glutathione has been detected by the writer in the species of insects mentioned in this paper. On evidence of the inhibiting action of arsenicals on the gaseous exchange mentioned above, it would appear that the toxic action of arsenicals is essentially due to an interference in cellular oxidations and reductions. If we inquire into the nature of susceptibility, whether or not it is in some way associated with or dependent upon the rate of oxidation in protoplasm, we again point to the fact that young insects showed a higher rate of oxidation and were more susceptible to arsenicals than older ones.

A chemical alteration of the protoplasm caused by the penetration of arsenic ions may render it more reactive or less reactive. From the data presented it is clear that, except in the case of realgar, the effect of the agents is to retard biochemical processes, the retardation caused by realgar occurring only after greater quantities of the poison have been ingested.

SUMMARY

The effect on the respiratory metabolism of potato beetles produced by feeding foliage sprayed with various arsenicals was studied. Experiments similar to those with potato beetles were made on wireworms by feeding grains of corn soaked in arsenical solutions.

The metabolic activity of potato beetles was reduced when they fed on lead arsenate, calcium arsenate, ferric arsenate, and manganese arsenate for 2 to 16 hours, and increased when they fed on realgar for the same period. The percentage depression of the oxygen consumption and the carbon dioxide production varied with the arsenical employed.

Realgar seemed to act as a stimulant at first, since both the oxygen intake and the carbon dioxide output increased and a gain in weight occurred. After three days' feeding, however, a depression of the gaseous exchange took place, indicating a cumulative action of this substance in the protoplasm.

Differences in susceptibility to lead arsenate appeared when sprayed foliage was fed to two groups of insects (young and old). In young insects the inhibiting influences were more profound. The inhibition exhibited by starving insects on the gaseous exchange was comparable to that of young insects.

The respiratory metabolism of insects was reduced when they were fed the oxide components of arsenical compounds; that is, lead oxide, manganese oxide, ferric oxide, and calcium oxide. The reduction with calcium oxide was, however, insignificant.

Arsenious acid, arsenic acid, sodium arsenite, and sodium arsenate depressed the oxygen consumption and the carbon dioxide production profoundly during the first few hours after insects were fed these solutions. The lowering of the oxygen intake continued gradually thereafter until a maximum depression was reached for the concentration of the solution. A significant increase in the respira tory quotient resulted from these tests.

With the concentration of arsenious and arsenic-acid solutions used it was found that arsenious acid was 57 per cent more toxic than arsenic acid. Similarly, sodium arsenite was found to be 59 per cent more toxic than sodium arsenate.

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A STEM-END AND CENTER ROT OF TOMATO CAUSED BY VARIOUS UNRELATED ORGANISMS[1]

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INTRODUCTION

When an abundance of bacteria is found in plant tissue still in an early stage of disease, it is generally accepted that the disease has been produced by a specific organism. In the work of isolating the organism from the diseased material, should the platings yield pure cultures or nearly so, the belief is strengthened; and later if the original type of lesion is reproduced by inoculation, the worker is fully convinced that a specific germ is the cause of the disease. This is true as a generalization, but in the particular case with which this paper deals, more than one organism was found to be the cause of the typical diseased condition.

DESCRIPTION OF THE DISEASE

The disease in question is a rot of tomato fruits; it usually starts when the fruits are green and is scarcely noticed until they are full-sized or just beginning to turn. The decay is mostly internal and is hard to detect on the outside of the green fruit unless the stem end is examined very carefully. Here it shows as small brown spots or a thin brown ring around the stem end or a discoloration of the stem scar (fig. 1, A; fig. 2, A). There are cases where the surface of the fruit may not show any definite marks of disease, but usually if no dark spots or rings are visible at the stem end, the fruit at or before the pink stage of ripening takes on a sickly color. When it is cut open the placentae are found partly or wholly decayed. The diseased portion is hard and brown and if the fruit is pink or red the diseased area is almost black (fig. 1, B). The rot may extend inside from stem to blossom end, though usually it is confined to the upper half of the central placentae. No external sign of disease was seen at the blossom end of any fruits examined or reported on. Quite frequently the rot involves a portion of seeds, and these, together with the surrounding tissue, become a hard black mass. This mass can be separated intact from the surrounding tissue (fig. 2, E). The disease does not affect the shape of the fruit and there is no slime or ooze connected with it. Razor sections through the hard dark portions examined under the microscope showed motile bacteria in the cells and between them (*2*).[2]

Although the central decay is the most important feature of this disease, the rot at the stem end is not to be overlooked. This stem-end rot, however, is unlike that of the tomato stem-end rots hitherto

[1] Received for publication July 14, 1926; issued December, 1926.
[2] Reference is made by number (italic) to "Literature cited," p. 1023.

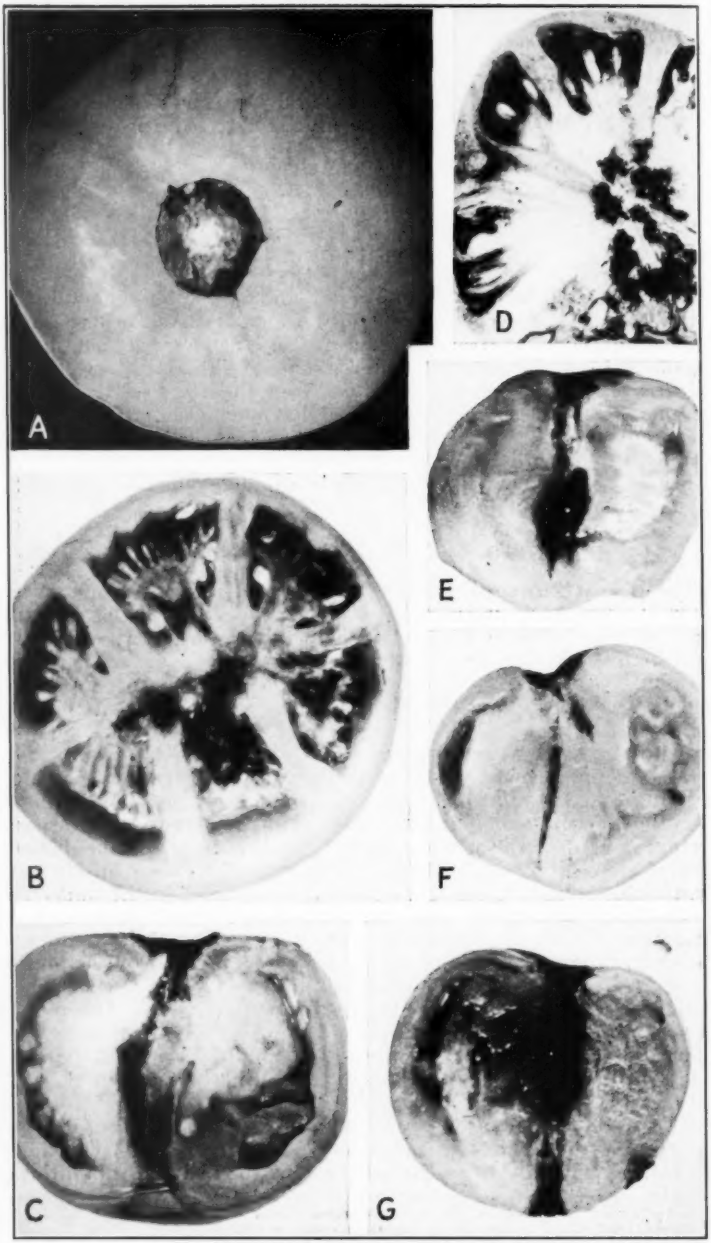

FIG. 1.—A, diseased tomato received from Texas in 1924. B, cross section of A. C, green tomato inoculated through stem end with the organism isolated from A; 4 weeks after inoculation. D, green tomato inoculated through stem end with the Texas organism; 5 days after inoculation. E, green tomato inoculated with *Bacillus coli;* 28 days after inoculation. F, green tomato inoculated with *Bacterium citri;* 32 days after inoculation; infection slight. G, green tomato inoculated with *Bact. savastanoi;* 24 days after inoculation

described. Of these one is a greenhouse rot caused by a Botrytis and the infection occurs on the calyx, fruit stalk, and stem end of either green or ripe fruit and advances into the fruit, softening it (*4*). Another is the *Phytophthora infestans* rot of tomatoes which is similar in its early stages on green fruit, but it attacks green or ripe fruit in any stage or size with the same ease, and the disease spreads beyond the stem in a broad dark area across the top of the fruit (*5; 11; 13, p. 9–16*). The fruit infection caused by *Cladosporium fulvum* Cke. is also more than a stem-end infection and spreads across the fruit, distorting and blackening the upper face of it. The hard central core is present, however (*8*).

ORIGIN OF THE DISEASE

The disease herein reported was first found in the tomato fields of Cherokee County, Tex. Since the fruit is shipped green, it was not observed until the tomatoes arrived at their destination and had changed to a pink color. The inspectors noticed the brown rings on the pink fruit and the unnatural shade of those still green and, cutting them open, found the decay well advanced through the central core (fig. 1, B).

There had been many light rains in this section accompanied by extreme heat. Some of the tomato growers attributed the disease to the weather conditions, others thought it might be due to an excess of sodium nitrate in the soil. Their losses from the disease were heavy; some days a third of the carloads arriving at market would be affected with the central decay.

In the summer of that year, 1924, the same disease occurred in Otoe County, Nebr., during the height of the shipping season (fig. 2, A). There were extreme changes in weather in the early summer; first it was very cold, then very hot, then too wet. In the late summer and early fall, when weather and growing conditions had altered, the disease became less virulent, and at the end of picking time the fields were nearly free from it.

Motile bacteria were found in the hard dark tissue of the Nebraska tomatoes, but no fungus was observed. In the region where the disease occurred in abundance there were some tomato growers with extended acreages who did not have a trace of it. They had not fertilized their soil at all or had turned under a cover crop and cultivated frequently during the growing period.

ISOLATIONS AND INOCULATIONS

The same bacterial organism was isolated from diseased fruit from both Texas and Nebraska, and the disease was reproduced by inoculating green tomatoes with bacteria from both isolations (fig. 1, C and D; fig. 2, B). The colonies on beef-agar plates were circular with entire margins, mostly smooth but some wrinkled (fig. 5, A and B). One-day-old colonies were cream colored in reflected light, but in transmitted light they had a broad cream-colored center with a blue area surrounding it. After a few days the entire colony was yellow.

The green fruits were first washed with mercuric chloride 1:1,000, then with sterile water, and a water suspension of the organism was smeared on with a soft sterile brush. Some of the tomatoes were punctured with a sterile needle at the stem and blossom ends, others

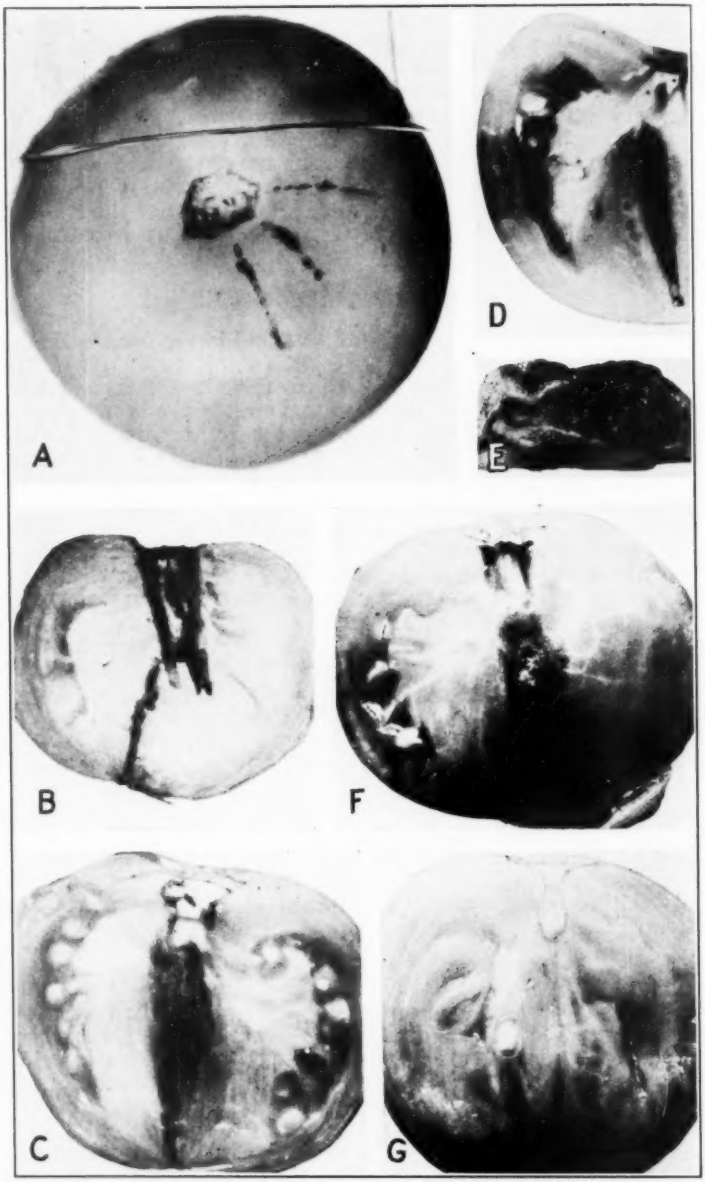

FIG. 2.—A, diseased tomato received from Nebraska in 1924. B, green tomato inoculated with organism isolated from A; 18 days after inoculation. C, green tomato inoculated with *Bacterium malvacearum;* 19 days after inoculation. D, green tomato inoculated with *Bact. vitians;* 27 days after inoculation. E, hard central core removed intact from tomato inoculated 14 days before with the Nebraska organism. F, control tomato punctured without sterilizing, and infection followed; 4 weeks after puncturing. G, control tomato sterilized before puncturing; no infection after 4 weeks

were smeared and not punctured (fig. 3, C). Two hundred and fifty-six tomatoes attached to the vines were inoculated with the Texas and Nebraska isolations. About 95 per cent of the punctured and inoculated fruits became infected, whereas not more than 30 or 40 per cent of the smeared ones became infected. Inoculations were made in green fruit on the vines from 3 cm. in diameter to full size; infection occurred in all sizes. It required from 5 days to 4 weeks for a good infection to develop, and if the fruit ripened within 5 to 7 days after inoculation there was little or no infection. Where inoculations were made by smearing and not puncturing, it usually required more time for the infection to appear. The best infections occurred at greenhouse temperatures of 23° to 30° C. with plenty of moisture. Below 20° the infection was slight. Bacteria were found in the tissues of inoculated fruits (fig. 4, A).

Control fruits in a bed removed from the inoculated ones were washed with mercuric chloride, 1:1,000, then with sterile water, and punctured with a sterile needle. Only 2 out of 22 treated in this way became infected with the dark center rot, and one of these only slightly. Two others had soft rot and 18 remained perfectly sound (fig. 2, G).

For comparison 67 other tomatoes in the same bed were punctured *without washing* in mercuric chloride and sterile water. Thirty-eight became diseased with the hard, dark center rot in varying degrees (fig. 2, F); 10 had soft rot, and 19 remained sterile. A reference to these controls occurs later.

Inoculations were made in the leaves and stems of tomato plants, but no infection resulted. At first the stems browned somewhat, but in a few days the browning disappeared. Cabbage, cauliflower, and lettuce plants were also inoculated but with negative results. Green sweet peppers, however, became infected and hard, blackened masses of placentae and seeds resulted. The peppers were left to ripen before cutting and examining. There was no soft rotting Bacteria were found in the cells of the dark portions.

Water suspensions of the organism were smeared over tomato blossoms with a soft camel's-hair brush to determine if infections could occur at this stage of development. Out of 116 blossoms treated in this way which later formed fruits, only one was infected. Isolations were made from this fruit and the typical yellow organism was recovered. Inoculations made with subcultures of this organism established the pathogenicity of the reisolation.

This disease, therefore, can occur through infection at almost any stage from the blossom to the nearly mature but not ripe fruit. All inoculations were made with the fruit on the vines. The most favorable stage for infection seemed to be when the tomatoes were green and had not reached their full size but were swelling rapidly.

HYDROGEN-ION CONCENTRATION AND INFECTION

The hydrogen-ion concentration in tomatoes is higher in the ripe fruit than in the green. For the former the P_H has been found to be 4 and 4.2, while for the latter it is between 5 and 5.4 (7).

As the upper limit of hydrogen-ion tolerance of the Texas and Nebraska organisms in culture is 4.9 and its optimum P_H is around

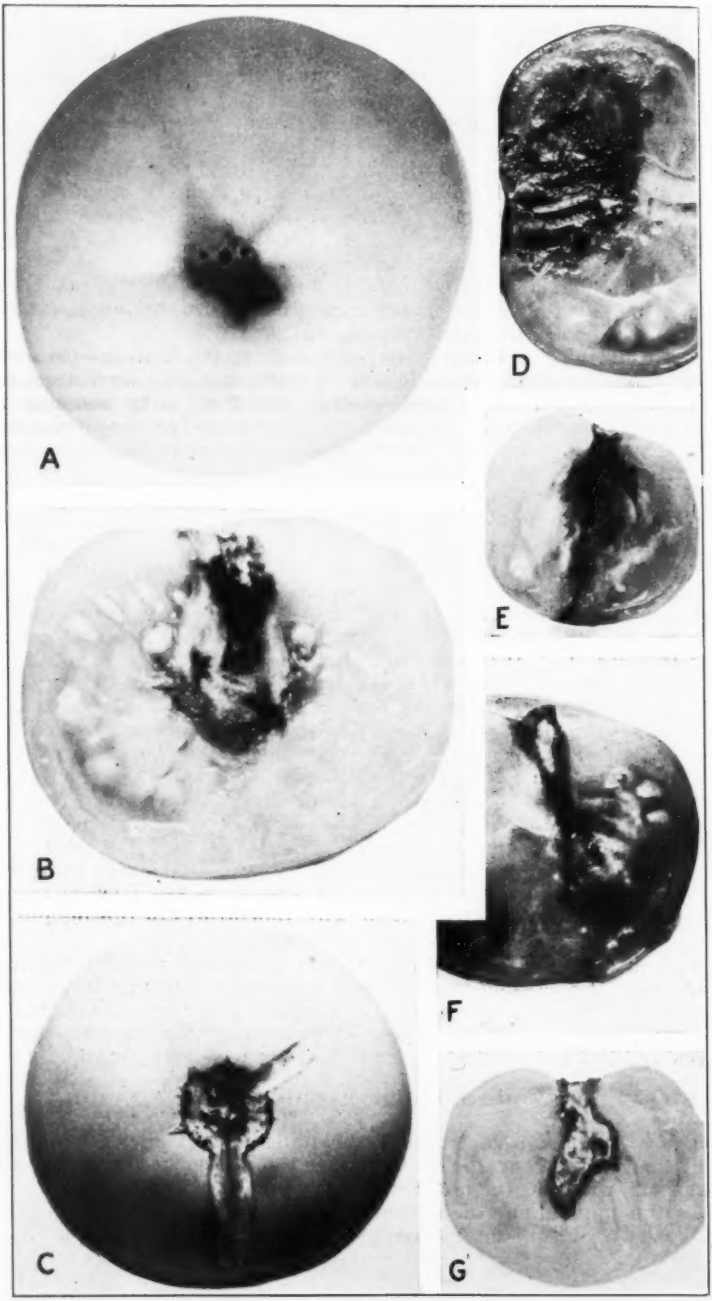

FIG. 3.—For explanatory legend see p. 1015

5.5, it is easily seen why infection began readily in the green fruit and developed slowly, or did not occur at all if the fruit was nearing maturity and beginning to redden.

After the Texas and Nebraska strains had been grown in culture media for two years barely a trace of infection followed the introduction of the organisms into fruit which was nearing maturity. For two years they had been grown on stock media with the P_H varying from 6 to 7, and they could no longer accommodate themselves readily to the more acid medium of the nearly ripe tomato juice. There was not the same difficulty with the green tomatoes, although the infections were not so pronounced as those which occurred immediately after the first isolation.

PLATINGS FROM SEEDS OF TOMATOES INOCULATED WITH TEXAS-NEBRASKA ORGANISM

To determine whether seeds from diseased tomatoes can carry the infection, plates were poured from seeds in diseased fruits; not the darkened seeds, but those which looked to be sound. The seeds were sterilized 1 and 2 minutes in mercuric chloride, washed in sterile water, then crushed in beef bouillon, from which the plates were poured. The typical yellow colonies appeared on the plates.

Plates were also made from seeds which were sterilized and washed but not crushed. These seeds showed no discoloration but were taken from badly diseased fruits. They were immersed 1, 2, and 5 minutes in mercuric chloride and then washed in sterile water and allowed to stand in beef bouillon for 15 minutes before the plates were poured. The Texas-Nebraska colonies appeared on the plates poured from the seeds treated for 1 and 2 minutes, but there were none on those poured from the seeds treated for 5 minutes.

Although the organism can be carried by the seed, little fear need be entertained regarding the spread of the disease by this method, for it is not likely that seed would be saved from a tomato which had even a small amount of internal decay.

Seeds of the variety Bonnie Best of the sowing used in Nebraska which produced the disease were tested out to see if this particular lot had carried the disease. Four different sets of plates were poured from 450 seeds out of a pound. The seeds were crushed and soaked in beef bouillon one to three hours before the plates were poured in order to give ample time for the bacteria to ooze out or off of them. No colonies of this organism appeared on the plates. Evidently the disease had not been carried into Nebraska from seed produced elsewhere.

The year after the heavy infection in Nebraska the same seed beds were used without sterilizing, and no disease appeared. It was therefore obvious that the seed beds were not responsible for the occurrence of the disease.

EXPLANATORY LEGEND FOR FIGURE 3

A, blossom end of tomato inoculated with organism from Nebraska tomatoes; 19 days after inoculation. B, stem end of tomato inoculated with reisolation from A (blossom-end infection), giving typical stem-end infection; 25 days after inoculation. C, stem end of green tomato smeared with Texas organism; not punctured; 35 days after smearing. D, longitudinal section through A, showing blossom-end infection. E, green tomato inoculated with *Alternaria* sp.; 10 days after inoculation. F, tomato inoculated with *Bacterium viridilividum;* 30 days after inoculation. G, green tomato inoculated with *Verticillium* sp.; 28 days after inoculation

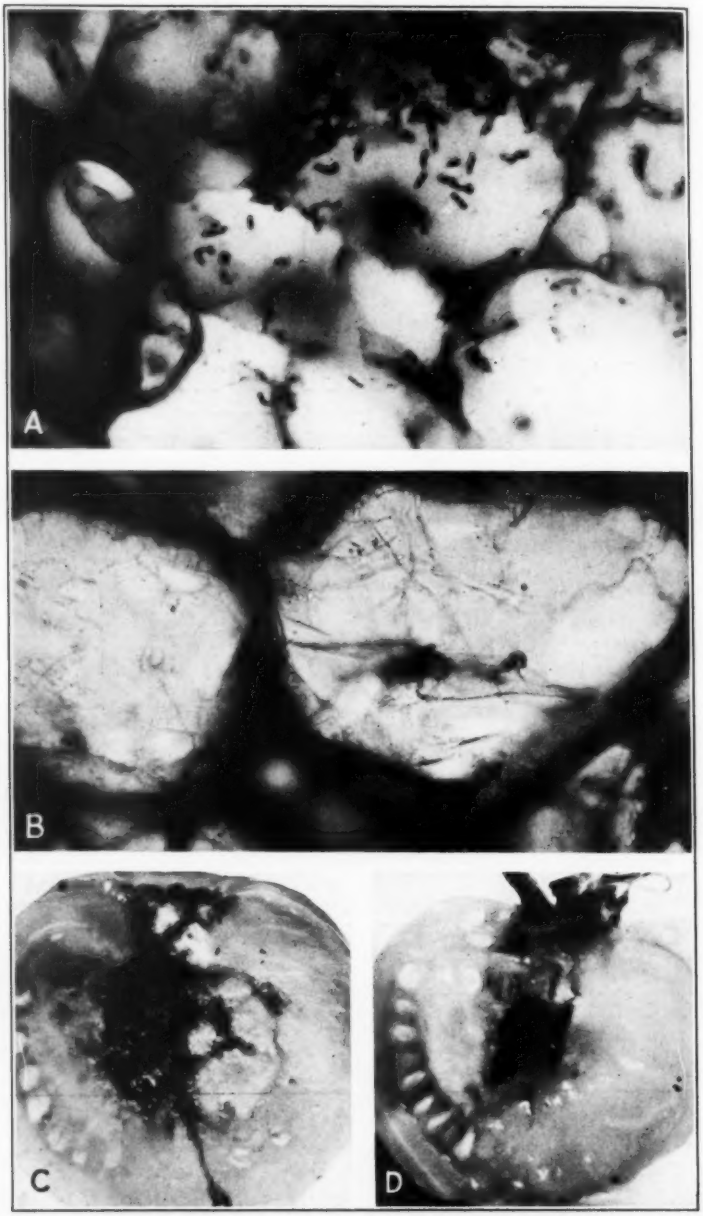

FIG. 4.—Bacteria showing in a stained section of tomato inoculated with the Nebraska organism; 18 days after inoculation; × about 1,500. B, mycelium of fungus showing in section of tomato inoculated with *Fusarium moniliforme;* 18 days after inoculation; × about 200. C, green tomato inoculated with *Cladosporium* sp.; 14 days after inoculation. D, green tomato inoculated with *F. moniliforme;* 14 days after inoculation; tomato very ripe and beginning to soften near calyx

CULTURAL TESTS

Extensive cultural tests with colonies of the Texas and Nebraska isolations were made. The two proved to be similar organisms throughout nearly the whole of the series of tests as laid down in the descriptive chart of the American Society of Bacteriologists. In a test made with sugars for the production of gas one colony of the Texas isolation showed a variation. It was an active gas producer while the others were not. The purity of this colony was tested and established, and it was then used for further inoculations to see if by chance it would still produce the disease. It was as virulent as the other colonies and readily produced the characteristic lesions of the disease. So this colony was considered a variant, a thing which sometimes occurs with bacterial organisms. No other disturbing factor arose with the Texas and Nebraska strains.[3]

A short time after the cultural tests were completed some controls were made by puncturing tomatoes with a sterile needle but without first washing them with mercuric chloride and sterile water. Careful watch was kept on these, and in two weeks infection began to appear. Figure 2, F, shows the condition of one of them four weeks after puncturing. Razor sections through the hard central decayed part were examined under the microscope and bacteria were found as in the inoculated fruit. Platings were made, but instead of a pure culture of one organism two distinct types of yellow colonies were found, one of which was undoubtedly the Texas and Nebraska type which had been used for producing infections on fruits of neighboring plants but not in the same bed. For some reason instead of discarding the other yellow type as an intruder it was picked off, subcultures made of it, and later tomatoes were inoculated with it. This supposed intruder type also produced the disease after the usual time had elapsed, and the situation was thought rather confusing.

Shortly after this occurrence several untouched fruits in the neighborhood of some that had been inoculated with the Texas and Nebraska strains became infected with the same type of disease. These tomatoes were studied and only bacteria were found in the diseased parts. Isolation plates made from one of them gave two types of yellow colonies, one the Texas and Nebraska organism and another unlike it. This unknown type also produced the disease when green tomatoes were inoculated with it. When this second yellow unknown organism produced the typical central rot it was decided to try out a number of known pathogenic organisms and, much to the surprise of the writer, various ones produced the hard dark central lesions typical of the Texas and Nebraska disease.

TESTS WITH DIFFERENT ORGANISMS

It was decided to try first several yellow plant pathogenes. The white colonies frequently found in association with the yellow ones on the plates had previously been tested for their ability to produce the hard central decay, but they had caused only a definite soft rotting. The yellow ones, on the other hand, had produced the typical hard central rot, as before stated.

[3] The record of the cultural tests need not be given in this paper nor need the organism be named, since it proved eventually to be only one of several organisms able to produce the disease.

In every case before inoculating, the fruit was washed with mercuric chloride, 1:1,000, then with sterile water. Green fruit and some just before it turned red were inoculated and left on the vines to ripen.

Bacterium campestre (Pam.) EFS., the cause of the black rot of cabbage and other crucifers, produced very good infections as did *Bact. marginale* Brown (fig. 5, F) and *Bact. viridilividum* Brown (fig. 3, F), the cause of a leaf spot and rot of lettuce. Reisolation plates were made from the "marginale" and "campestre" tomatoes and the organisms were recovered.

Bacterium citri Hasse (fig. 1 F), the organism producing citrus canker, gave a few good infections and some slight ones, but for the most part the results were negative. Conditions evidently had to be very favorable for this organism. The same was true of *Bact. vitians* Brown (fig. 2, D), an organism causing a stem rot and leaf spot of lettuce.

Bacterium malvacearum EFS. (fig. 2, C), the cause of a leaf spot of cotton, produced the characteristic hard centers, but they were only occasionally dark colored.

Bacterium savastanoi EFS. (fig. 1, G), an organism which produces tubercles on the olive tree, produced a very good hard central decay of tomatoes.

Bacterium gummisudans McCulloch, which causes a leaf spot of galdiolus, did not produce the disease. It was tested under various growth and temperature conditions, but the results were always negative.

Aplanobacter michiganense EFS., which produces a wilt of the tomato stem and a yellowing of the fruit, did not induce any hardening or browning of the central tissue.

The well-known colon bacillus, *Bacillus coli communis* Esch., was able to produce a slight infection in 2 cases out of 15 (fig. 1, E). *B. mycoides* Flügge, a common soil organism, gave negative results in all but 5 out of 19 inoculations.

At the conclusion of the experiments with the yellow organisms several white pathogenes were tested.

Bacillus tracheiphilus EFS. did not produce the disease. It was tried at different seasons and under different temperature and moisture conditions.

Two strains of *Bacterium tumefaciens* Smith and Townsend, which are common in the soil, were tried. One was isolated from the hop gall and another from the peach gall. The hop strain produced the typical tomato lesions very quickly, but no galls formed (fig. 5, E). The organism was reisolated, and on the reisolation plates the usual smooth, round colony was found somewhat changed by passing through this host, and appeared as a wrinkled and humpy one (fig. 5, C and D). Subcultures of it produced good galls on Ricinus, but none on geranium or tomato stems, as the original and typical crown-gall hop strain does. The tomato stem was browned for more than 3 cm. on either side of the inoculation point but not galled. The peach strain of *Bact. tumefaciens* also produced the typical hard brown internal decay in the tomato fruit (fig. 5, G). Altogether, 35 green tomatoes were inoculated with *Bact. tumefaciens;* 16 with the hop strain and 19 with the peach strain. The hard brown centers resulted in all but two. These two remained sound and healthy.

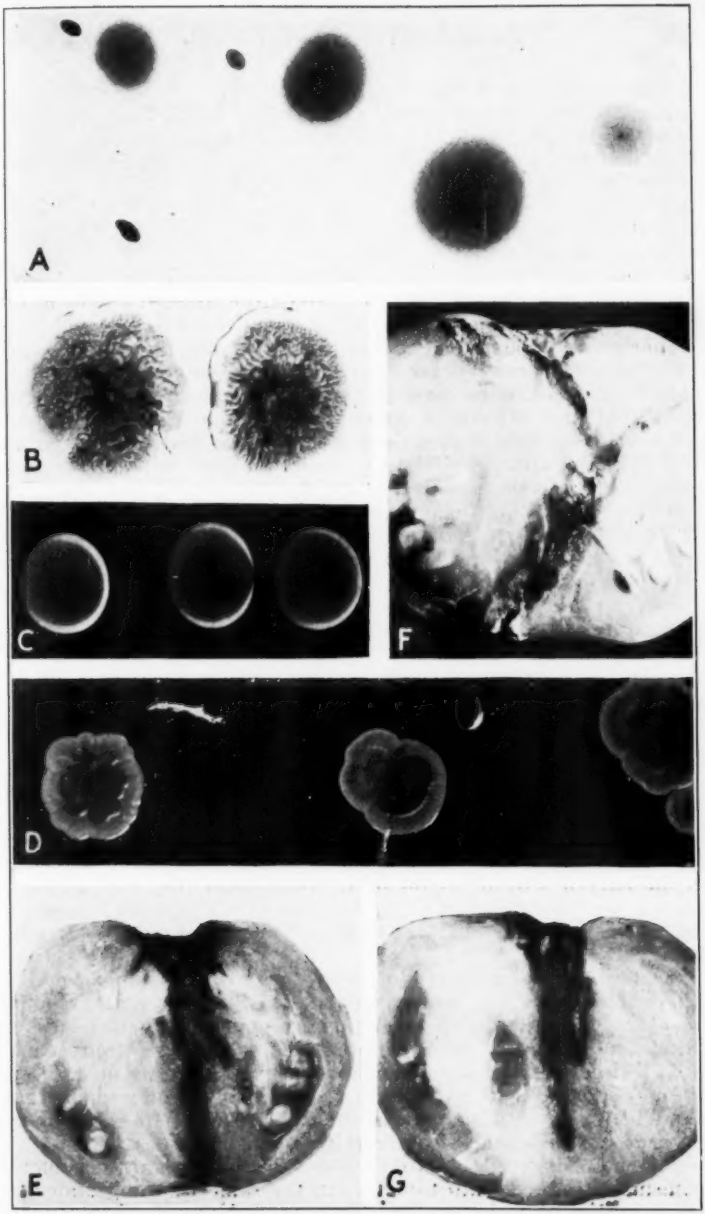

FIG. 5.—A, colonies of the Nebraska-Texas organism on beef-ager plates, enlarged about five times; smooth type; infectious. B, wrinkled type of Nebraska-Texas organisms on beef-agar plates, enlarged about five times; this type also infectious. C, typical colonies of *Bacterium tumefaciens*, hop strain on beef-agar plates; enlarged about five times. D, wrinkled type of *Bact. tumefaciens* colonies; hop strain on beef-agar plates; wrinkled character produced by passage of the strain through tomato fruit. E, green tomato inoculated with hop strain of *Bact. tumefaciens;* 18 days after inoculation. F, green tomato inoculated with *Bact. marginale;* 30 days after inoculation. G, green tomato inoculated with peach strain of *Bact. tumefaciens;* 18 days after inoculation

A few fungi were tested in the same way. A *Verticillium* sp. causing a wilt of tomato stems, and another Verticillium causing a wilt of heliotrope (fig. 3, G.) produced the hard, dark core without any softening of the tissue. The fruit was always left on the plants to ripen before the examination inside was made.

An Alternaria isolated from stems of *Rosa hugonis* was tried and found to produce the hard, dark central rot (fig. 3, E). The fungus was recovered on reisolation plates.

An Alternaria has been noticed before in connection with a tomato central rot. A few years ago F. J. Pritchard examined lesions of this sort and found a fungus associated with it which he identified as an Alternaria. He was unable at the time to pursue the investigation. Several summers later he received similar diseased tomatoes from Nebraska and found bacteria in the cells, but no fungus. He concluded that the Alternaria which he had found previously must have been a secondary organism, and that he had overlooked the bacteria. The writer received the Nebraska material from him, and it was the bacterial organism isolated from these tomatoes which proved to be similar to the one isolated from the Texas tomatoes.

A *Cladosporium* sp. pathogenic to cranberry fruit produced the typical lesions in 25 out of 30 inoculated green tomato fruits. The color was almost black (fig. 4, C). The fungus was reisolated.

Septoria gladioli Pass., which produces spotting of leaves and dry rot of corms, gave negative results when inoculations were made in the winter. In the spring, however, the conditions were more favorable, and the broad, hard central core resulted. There was not the very dark color, however, which accompanied the Verticillium and Cladosporium infections.

Fusarium moniliforme Sheldon, a fungus which produces a soft rot of the Smyrna fig, also produced the typical lesions, and when the tomatoes were absolutely ripe there was also a soft rotting. The tissue in some parts of the tomato just below the epidermis became watery looking, and microscopic examination showed not the presence of a soft-rot bacterial organism but an abundance of mycelium and the curved septate spores of *F. moniliforme* (fig. 4, B). If the tomatoes were cut when red, but not perfectly ripe, only the central hard decay was present (fig. 4, D). The Fusarium was readily reisolated.

The hard central core produced by these various fungi could be lifted out intact, as in those fruits inoculated with bacteria. The texture of the core produced by a fungus sometimes had a leather-hardness instead of the crystallike or woody hardness produced by the bacteria. Occasionally small hollow spaces occurred in the ceny tral core, and the leathery texture was probably produced by these hollows being filled with a mycelial mass. In the tomatoes inoculated with bacteria these spaces were rarely present.

From the tests, it is seen that out of 13 different known bacterial organisms introduced into tomatoes in the same way and under the same conditions as the original Texas and Nebraska isolations, 6 produced positive results; results typical of those obtained by inoculation with the Texas and Nebraska strains. Four other organisms gave positive results under very favorable conditions, and three gave negative results. Of the five fungi tested all produced similar disease, and one produced a soft rot in addition.

The number of bacteria and fungi tested in this way might be extended indefinitely. Enough have been worked with, however, to establish the necessary proof that the stem and central decay of tomatoes is a parasitic disease induced while the fruit is green by various organisms under conditions of high temperature and high moisture. Those bacterial organisms which gave negative results and those which gave positive results only occasionally might, under certain conditions, be as positive as the Texas and Nebraska organisms themselves. The tomato varieties used in this work were Livingston's Globe and Bonnie Best. Both seemed equally susceptible. It is possible that another variety of tomato might have been favorable to the production of the disease if inoculated with those organisms which gave negative results with the above-named varieties. Certain fertilizers, too, might influence infection; so that it could be induced by those organisms which in the experiments with Bonnie Best and Livingston's Globe had proved noninfectious.

There was very little trouble from bacterial soft-rot organisms getting into the punctures. The careful washing of the tomatoes with mercuric chloride and sterile water before inoculation evidently prevented this from happening. The controls so treated were a striking evidence of the slight extent to which it occurred. Had the work been done out of doors more secondary infection might have developed.

ENTRANCE OF ORGANISMS INTO THE TOMATO

It is likely that the attacking organisms made their entrance at the region where the cuticle ends and the stem begins, for it was there that the black ring occurred.

The warm weather and excessive moisture in Texas and Nebraska undoubtedly produced rapid growth in the tomatoes, resulting in tiny breaks in the tissue at the cuticle margin, through which surface organisms can enter. In some instances the rapid growth might have stretched the cuticle at its juncture with the torus, thinning it so that the entrance to an active organism was made easy. In other cases it may have been that raindrops persisted at this juncture area long enough to injure some of the cells, and a slight extrusion of cell content could easily furnish enough food for the bacteria to begin their activities.

The stomata of the calyxes are another avenue of entrance to germs. From the calyx a passage can easily be gained to the torus and thence into the fruit. The calyxes of many inoculated fruits were examined and bacteria were found in them, causing first a watery appearance and in a later stage a hard, dry one.

OBSERVATIONS ABOUT BLOSSOM-END ROT OF TOMATOES

It seems to the writer that the same conditions which produce the stem-end and center rot of tomato may be responsible for the blossom-end rot, which of late years has been classified as a nonparasitic disease, the cause being laid to the breakdown of the tissue due to irregularities in the water supply; the bacteria and fungi which are present being considered secondary (*1*). The blossom-end rot has been studied by pathologists extensively in different countries and bacterial or fungous organisms have always been found associated with it (*3, 6, 9, 10, 12*).

Figure 3, A and D, shows an inoculation at the blossom end of a tomato with the bacterium isolated from Nebraska tomatoes which were affected at the stem end and center. The appearance is not unlike that of blossom-end rot. To establish further evidence that this condition at the blossom end was really produced by the Nebraska germ with which it was inoculated, isolation plates were made and the organism was recovered. The pathogenicity of the recovered germ was further tested and proved by inoculations into the stem end of other tomatoes (fig. 3, B).

GENERAL PREVENTIVE AND CONTROL MEASURES

As both soil and weather conditions are responsible for the presence of the stem-end and center rot of tomatoes in a field, the grower may be able to prevent or lessen it very materially by using manure which has passed through all the active stages of disintegration. This will assure him of fewer active soil organisms on his fruit and consequently of less disease should the weather conditions be favorable for them to get into it. Cover crops should be turned under at least a month before planting.

If an uninterrupted growth of tomatoes can be kept up during the fruiting season there will be little chance of the disease making any headway. A period of hot, dry weather holds back the growth of the plant, necessarily retarding the growth of the outer part of the fruit. Then if wet weather comes and rapid growth follows, the fruit fills up with water, and as the epidermis can not keep pace with the swelling cells inside, tiny cracks result. Frequent cultivation will keep the plants growing and prevent the fissures from forming. Evidence of this was very striking in Nebraska, where well-cultivated fields had practically no diseased fruit at the time of the heavy infection of other fields which were cultivated only sparingly.

The grower should also be careful to select varieties which are known not to crack easily.

As the disease can be produced by various bacterial and fungous organisms, it is highly essential to have clean seed, and any seeds that are slightly discolored or undersized should be avoided. Sanitary field methods should be followed.

The use of Bordeaux mixture is considered an effective germicide for tomato diseases. If the bacterial and fungous flora of the surface of green tomatoes is reduced or weakened by frequent spraying with this mixture there will be very little chance of the disease occurring.

SUMMARY

A stem-end and center decay has been responsible for heavy losses in shipments of green tomatoes. The disease can scarcely be detected on the outside of the fruit, while the central core, including portions of the seeds, is a mass of hard, dark tissue.

The disease occurs usually during seasons of hot weather and abundant rain, or during weather in which the fruit expands too rapidly after a period of checked growth. There is always an organism present which is responsible for the decay. It may be either a bacterium or a fungus. In a given location it may be a certain organism active and prevalent in that particular soil, whereas in another location it may be a different and entirely unrelated organism.

The work reported in this paper began with a yellow bacterial organism isolated from tomatoes similarily diseased in Texas and Nebraska in 1924. This organism was considered the specific cause of the disease for over a year. Since then, six different bacterial and five different fungous organisms have been inoculated into green tomatoes, and each has readily produced the stem-end and center rot. Four other bacterial organisms produced the lesions only after repeated trials and when conditions happened to be favorable to them. The results with three others were always negative.

The organisms which produced the decay readily were *Bacterium malvacearum* EFS.; *Bact. marginale* Brown; *Bact. tumefaciens* Smith and Townsend; *Bact. savastanoi* EFS.; *Bact. campestre* EFS.; *Bact. viridilividum* Brown; *Cladosporium* sp.; *Septoria gladioli* Pass.; *Verticillium* (two species); *Fusarium moniliforme* Sheldon; and *Alternaria* sp. The four organisms which produced the disease with difficulty were *Bact. citri* Hasse; *Bact. vitians* Brown; *Bacillus coli communis* Esch.; and *B. mycoides* Flügge.

The organisms which failed to produce the disease were *Bacillus tracheiphilus* EFS., *Bacterium gummisudans* McCulloch, and *Aplanobacter michiganense* EFS.

It is likely that there are many other bacteria and fungi able to produce the same lesions in tomatoes given the right conditions for development. The acidity of the fruit and proper conditions of growth are probably factors in preserving it from many of the organisms present in richly fertilized soil.

Blossom-end rot of tomatoes, considered by pathologists to be a physiological disease induced by irregularities in the water supply and not by parasites, was produced by inoculating tomatoes with the Texas-Nebraska organism. As the stem-end and center rot can be produced on growing green tomatoes by various bacteria and fungi when temperatures are high and moisture is abundant, it is quite possible that the blossom-end rot is produced in the field in the same way.

Preventive measures may be taken by using varieties which do not crack readily, fertilizing with well-seasoned manure in which the organisms are less active, cultivating the soil frequently, using sanitary methods in the field, and spraying with Bordeaux mixture.

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THE RELATION OF BLACK ROT TO THE STORAGE OF CARROTS[1]

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INTRODUCTION

The black rot of carrot (*Daucus carota* L.) caused by *Alternaria radicina* M. D. and E., was discovered in 1918 by Meier, Drechsler, and Eddy on Long Island, N. Y., and by the writer in Washington, D. C. Meier, Drechsler, and Eddy discovered the causal organism produced the disease on the roots and foliage, and found that infection of roots in storage resulted from infection of the foliage. A description of the disease and excellent drawings of the fungus have been published.[2]

The disease as it occurs on the roots of carrot is of considerable economic importance. It has been observed on the New York and Washington markets nearly every season since its discovery. No accurate survey has been made of the extent of the loss caused by this rot, but the following example illustrates how serious it may become. A half ton of carrots (Danvers Half-Long variety) was purchased on the Washington market in November, 1921, and stored at temperatures ranging from 0° to 2° C. at Arlington Experiment Farm, Rosslyn, Va. The carrots were grown at Williamson, N. Y., shipped to Washington in bags in a carload lot, and removed to storage soon after arrival. At the time of storing they were in excellent condition and no black rot was observed. Two months later, however, the disease became evident. On May 20, 1922, after 185 days in storage, four crates were selected at random and a count was made of the diseased and healthy roots. Three hundred and two out of 488 carrots, or 62 per cent, had black rot (Table 1). The 62 per cent did not necessarily represent a total loss, for it included all infected roots no matter how few or how small the lesions. Roots with few and small lesions can be utilized, but since they are marred in appearance, their market value is of course reduced.

The decay caused by *Alternaria radicina* represents only a part of the loss that may result from the presence of the disease, for black-rot lesions afford a favorable opportunity for the entrance of other fungi such as Sclerotina and Botrytis. Botrytis especially is dependent on some such favorable means of entrance. Blackman and Welsford[3] have shown that this fungus in order to attack the leaves of *Vicia faba* L. readily must have a start on dead organic matter. Such a start is conducive if not indispensable to infection of carrots by Botrytis. The usual method of infection is through dead root tissue (the root tip, rootlets, and the crowns.) The black-rot lesions often crack and leave dead carrot tissue exposed to the action of fungi that

[1] Received for publication July 3, 1926; issued December, 1926.

[2] MEIER, F. C., DRECHSLER, C., and EDDY, E. D. BLACK ROT OF CARROTS CAUSED BY ALTERNARIA RADICINA N. SP. Phytopathology. 12: 159–166, illus. 1922.

[3] BLACKMAN, V. H., and WELSFORD, E. J. STUDIES IN THE PHYSIOLOGY OF PARASITISM. II. INFECTION BY BOTRYTIS CINEREA. Ann. Bot. [London] 30: 389–398, illus. 1916.

may be present. Botrytis always occurs to some extent in carrots under storage conditions, and roots kept for long periods at temperatures ranging from 0° to 5° C. invariably become infected with it. The decay caused by this fungus is much greater in carrots affected with black rot than in those not so diseased.

TABLE 1.—*Amount of infection that developed during storage on the roots of carrots when the foliage was inoculated with Alternaria radicina* [a]

Where carrots were grown	Season	Treatment of carrots	Duration of storage in days	Number of roots stored	Number of roots infected	Percentage of roots infected
U. S. Department of Agriculture grounds.	1920–21	Foliage inoculated	215	414	412	99.5
		Foliage not inoculated	215	448	260	58.0
Arlington Experiment Farm.		do	215	523	13	2.5
U. S. Department of Agriculture grounds.	1921–22	Foliage inoculated	201	341	152	44.6
		Foliage not inoculated	201	331	8	2.4
Arlington Experiment Farm.		do	201	2,360	5	.2
Williamson, N. Y.	1921–22	do	185	488	302	62.0
U. S. Department of Agriculture grounds.	1922–23	Foliage inoculated	120	426	422	99.0
		Foliage not inoculated	120	144	19	13.2
Arlington Experiment Farm.		do	120	151	1	.6

[a] Storage temperatures ranged from 0° to 2° C. in each experiment.

DESCRIPTION OF THE DISEASE

ON THE LEAVES

There is little to add to the previous description of the disease as it occurs on the leaves.[4] The resemblance of the symptoms of the black-rot disease to those of carrot blight (*Macrosporium carotae* E. and L.) might be emphasized, especially during the final stages when the outer leaves are killed. The writer has been unable to distinguish from macroscopic examination leaves killed by *Alternaria radicina* and *M. carotae*. The two diseases resemble each other in that there is a tendency for the outer leaves to be killed, but differ in that the blight lesions are more widely distributed over the foliage than are those produced by the black-rot organism. During blight epiphytotics the entire tops are often killed.

ON THE ROOTS

The lesions as they occur on the sides of the roots are circular to irregular in outline, slightly depressed, usually shallow, penetrating from 1 to 3 mm. deep (fig. 1). When infection occurs at the crown, the decay generally penetrates rather deeply, particularly into the core.[5] As a rule, the color of the decay is almost jet black, but sometimes it is a greenish black. The black fungous growth may or may not occur on the surface of the lesions.

ORIGIN OF THE DISEASE ON THE ROOTS

PLACE OF STORAGE

The storage house may be a source of the disease if it has been used for the storage of diseased roots. Uncontaminated and healthy roots do not become diseased if stored in a house that has not been contaminated by the previous storage of diseased roots. It would seem, therefore, that the disease has its origin in the field.

[4] MEIER, F. C., DRECHSLER, C., and EDDY, E. D. BLACK ROT OF CARORTS CAUSED BY ALTERNARIA RADICINA N. SP. Phytophathology 12 : 159–166, illus. 1922.
[5] MEIER, F. C., DRECHSLER, C., and EDDY, E. D. Op. cit.

DISEASED FOLIAGE

Evidence has been submitted to show that infection of the roots in storage results from infection of the foliage.[6] The following experiments, conducted during three seasons, substantiate this evidence.

The carrots used in these experiments were grown in the grounds of the United States Department of Agriculture at Washington, D. C., on a small piece of ground suitable for carrot culture, but probably never employed for that purpose. They were planted between the first and twentieth of June each season. The ground was divided into two plots, one of which was inoculated and the other held as a check. The foliage was inoculated by thoroughly spraying it with a spore suspension of *Alternaria radicina* in humid weather during late August or early September[7]. For this purpose an atomizer was used.

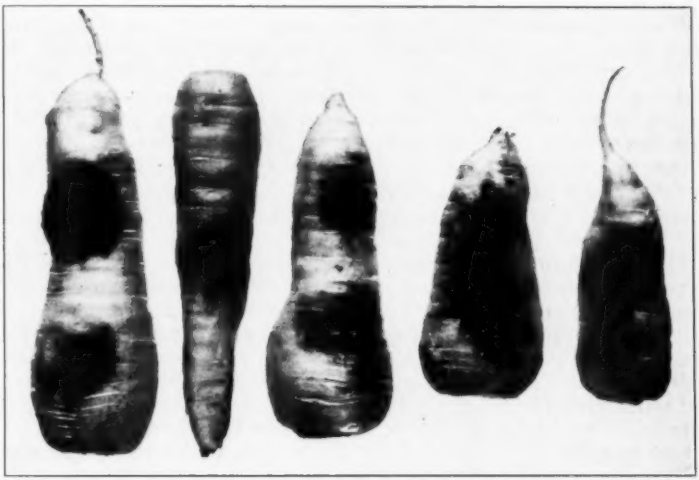

FIG. 1.—Typical lesions of black rot as they occur on the sides of carrot roots.

A pathological condition of the foliage resulted from the inoculations very similar[8] to that produced by *Macrosporium carotae*, which was also present to some extent each season. The disease spread after a time to the checks, but here it never became as severe as in the inoculated plot.

Diseased leaves from these plots were examined in the laboratory from time to time each season. *Alternaria radicina* was found on many of the lesions and was isolated a number of times from diseased tissue, usually from the lower leaves. *Macrosporium carotae* was occasionally obtained instead of *A. radicina*.

The roots were dug and stored in early November, and no disease was observed on them at that time. They were again examined at the end of the storage period (April and May). The results are

[6] MEIER, F. C., DRECHSLER, C., and EDDY, E. D. Op. cit.

[7] 1920. Aug. 25, day of inoculation, sky cloudy; Aug. 26, heavy fog during morning, settling down to earth, foliage wet, drops of water on all the foliage; Aug. 27, fog during morning and rain during night.
1921. Aug. 27, day of inoculation, rained night before and up to time of inoculation; cloudy all day and most of following night.
1922. September between seventh and fifteenth; cloudy during two days following inoculation.

[8] MEIER, F C., DRECHSLER, C., and EDDY, E. D. Op. cit.

recorded in Table 1. Table 1 also contains data on carrots grown at Arlington Experiment Farm, Rosslyn, Va., and carrots grown at Williamson, N. Y. which were stored under the same conditions (temperature 0° to 2° C.) as those from the inoculated and check plots.

An examination of Table 1 reveals the fact that there was an abundance of black rot in roots from inoculated foliage and a liberal amount in roots from the check, showing again that the disease spread from the inoculated to the check plot. A trace of black rot was found in stored carrots grown at Arlington Experiment Farm following the storage of diseased roots in the same room. It is believed that this trace had its origin in these diseased roots.

The foregoing data would indicate that diseased foliage is a source of root infection were it not for the fact that the foliage disease has never been observed to occur naturally. In 1919 a careful examination was made of plants growing in fields where carrots which developed black rot had grown the previous year [9] but no evidence of disease could be found. Several attempts have since been made to find the foliage disease but without success. The disease of the roots on the other hand, has been observed nearly every season since it was discovered. The contingency of the root disease upon the foliage disease must therefore be subject to question until the latter is observed to occur naturally.

INFECTED SOIL

The data recorded in Table 2 prove that it is not necessary for the disease to pass directly through foliage into the roots in order for them to become infected. These data were obtained from two of the experiments discussed on page 1027. The foliage was inoculated in late August; the roots were harvested in early November and stored at temperatures ranging from 0° to 2° C. until June the first season and until April the second. It will be seen from the data that more infections occurred at the sides of the roots than at the crowns. It is also possible that some of the infections at the crown occurred independently of the infection of the foliage. It is just as conceivable that the infections of the roots, and especially those on the sides, might originate from a contaminated soil as from a diseased foliage.

TABLE 2.—*Points on the roots of carrots at which infection produced by Alternaria radicina occurred*

Season	Number of roots infected on—					
	Crown	Side	Crown and side	Crown and tip	Crown, tip, and side	Tip and side
1921 and 1922	32	179	89			
1922 and 1923	11	17	67	5	247	60

Alternaria radicina is a vigorous saprophyte and will live indefinitely on dead organic matter. It is not unreasonable, therefore, to believe that it may live in the soil, and thus the soil may be a source of inoculum for the infection of the roots. Experiments are under way to determine whether or not soil may be a source of root infection.

[9] MEIER, F. C., DRECHSLER, C., and EDDY, E. D. Op. cit.

TABLE 3.—*Infection of carrots by Alternaria radicina through wounds, rootlets, and uninjured skin*

[Inoculations made by means of a spore suspension in carrot decoction in a glass tube sealed on the carrot with vaseline]

Temperature, °C.	Duration of experiment in days	Inoculated over freshly cut surface		Inoculated over uninjured skin		Inoculated over old wound		Inoculated over rootlets	
		Number of carrots used	Number of carrots infected	Number of carrots used	Number of carrots infected	Number of carrots used	Number of carrots infected	Number of carrots used	Number of carrots infected
13	30	5	5	10	4				
20	28	8	8	17	10	7	5	7	4

METHOD OF INFECTION

It was shown in Table 2 that infection could occur anywhere on the roots. The results recorded in Table 3 indicate not only that *Alternaria radicina* can infect carrot roots through fresh wounds, old wounds, and by way of the remains of small rootlets that are always present on the roots, but that it is able to penetrate the uninjured skin. Infection occurs more slowly through the uninjured skin than by the other methods mentioned, indicating that the skin offers some resistance; in fact only the outer cells (four to five cells deep) were penetrated. The mycelium was found to encircle the cytoplasm in some instances, and in others to ramify through the entire cell. Fresh wounding is shown to be the most predisposing condition to infection.

TABLE 4.—*Influence of method of inoculation and types of wounding on infection of carrot roots by Alternaria radicina*

Container	Temperature ° C.	Duration of experiment in days	Inoculated with a spore suspension											
			Method of wounding									Not wounded		
			Crowned			Slice from side of root			Skin scraped from side of root					
			Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected
Wire basket	20	24	62	25	40							49	10	20
Wire basket	22	16	80	39	44	41	21	51	70	16	23	83	28	34
Moist chamber, cover on	22	16	7	4	57	7	2	29						
Moist chamber, cover off	22	16	8	6	75									

TABLE 4.—*Influence of method of inoculation and types of wounding on infection of carrot roots by Alternaria radicina*—Continued

Container	Temperature, ° C.	Duration of experiment in days	Inoculated with a flake of mycelium and spores												Inoculated by inserting mycelium and spores into tissue of roots		
			Method of wounding														
			Crowned			Slice from side of root			Skin scraped from side of root			Inoculated on uninjured skin					
			Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected
Wire basket	20	24	53	52	98	----	----	----	47	37	79	----	----	----	----	----	----
Wire basket	22	16	----	----	----	----	----	----	----	----	----	----	----	----	19	13	68
Moist chamber, cover on	22	16	----	----	----	19	19	100	----	----	----	7	1	14	----	----	----
Moist chamber, cover off	22	16	----	----	----	8	8	100	----	----	----	3	0	0	----	----	----

The results recorded in Table 4 were obtained from experiments designed to determine the influence which the kind of wounding and the method of inoculation have on infection. An examination of the data obtained from the various methods of wounding where the carrots were inoculated by being dipped in a spore suspension reveals considerable variation in the amount of infection. In one instance there was more infection when the carrots were not freshly wounded than when the skin was scraped off. It is believed, however, that these data taken collectively indicate that wounding increases the amount of infection. A partial explanation of the large percentage of infection among the unwounded carrots may be offered on the basis that most of the carrots in storage show some wounding. In fact it is almost impossible to harvest them without some wounding. The unwounded carrots in this instance represent the general run as they occur in storage, no precautions having been observed to eliminate roots with old injuries unless the injury was extensive. An effort was made in some instances to select roots free from injury, but it was next to impossible to do so. It has been observed that *Alternaria radicina* is able to infect carrots through rootlets, and to some extent through the uninjured skin. It is therefore to be expected that the effect of wounding would be merely to increase the chances of infection.

When the carrots were inoculated by placing a small flake of mycelium and spores on the roots, the percentage of infection was higher on all wounded surfaces than when the carrots were inoculated by means of a spore suspension. The percentage of infection on uninjured surfaces was less. Of course the data in these two instances are hardly comparable because the entire carrot, when it was inoculated by means of a spore suspension, was exposed to the inoculum, while in the other case the mycelium and spores were placed only on the uninjured skin.

In the last column of Table 4 are recorded the results obtained when carrots were inoculated by the insertion of a bit of mycelium and spores into the root tissue. This lot was run merely as a check to show that the inoculum was virulent. The percentage of infection is low for this type of wounding and method of inoculation (Table 9).

TABLE 5.—*Influence of temperature and wounding on infection of carrot roots by Alternaria radicina*

Temperature, ° C.	Depression of wet bulb, ° C.	Relative humidity	Duration of experiment in days	Inoculated but not wounded			Wounded and inoculated		
				Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected
20	0.9	92	17	18	4	22	12	4	33
18	.8	92	17	18	0	0	12	8	66
14	.7	91	33	18	1	6	12	8	66
9	.9	90	33	18	1	6	12	6	50
9	.9	90	33	18	0	0	12	2	17
5	.7	88	33	18	0	0	12	0	0
5	.5	92	96	17	6	35	12	4	33
Totals				125	12		84	32	
Averages						10			38

Table 5 contains the results of experiments designed to determine the influence of fresh wounding on infection at different temperatures. The roots were wounded by jabbing a nail into each ten times after the carrots had been inoculated by dipping them in a spore suspension. It will be seen that there is more infection in the wounded carrots at all temperatures except at 5° C., and here the percentage is about the same in the wounded and the unwounded. Temperature seems to have little effect on the number of infections if sufficient time is allowed to permit the maximum to develop at the different temperatures. There is less infection at 20° than at 18° in spite of the fact that 20° is nearer the optimum than 18°. Considering the data collectively, there was 38 per cent infection when the carrots were freshly wounded in contrast to 10 per cent when they were not wounded.

The method of wounding in this experiment was severe, but it shows quite clearly that wounding may become a factor of importance. Just such wounding often occurs in commercial practice when a fork is used in handling the crop.

Another type of wounding occurs during the process of harvesting. Some growers cut off the tops by means of a hoe before the roots are taken from the ground. During this operation many of the crowns are removed and the roots are otherwise injured. This type of wounding is worse than any other, because usually the decay penetrates more deeply when it enters through the crown than through the side of the roots.

TABLE 6.—*Relation of temperature to the growth of Alternaria radicina on carrot agar*

Temperature	Area of colonies	Duration of growing period	Temperature	Area of colonies	Duration of growing period
°C.	*Sq. mm.*	*Days*	°C.	*Sq. mm.*	*Days*
39.0	0	8	5.0	0	8
33.6	174	8	14.4	1,460	17
30.0	2,578	8	12.0	1,092	17
28.0	4,144	8	9.0	942	17
24.7	3,193	8	5.0	71	17
23.0	2,801	8	9.4	3,486	37
20.0	1,831	8	4.4	1,301	37
18.4	1,261	8	3.0	1,279	37
14.4	387	8	1.1	318	37
12.0	258	8	−0.5	61	37
9.0	87	8			

INFLUENCE OF TEMPERATURE ON THE GROWTH OF THE PATHOGENE IN CULTURE[10]

Three experiments were conducted to determine the range of temperatures at which *Alternaria radicina* will grow on carrot agar and to ascertain the optimum temperature for growth. Table 6 shows the results obtained in these experiments. The results at the temperatures 9.4°, 4.4°, 3°, 1.1°, and −0.5° C. were obtained in one experiment; those at the remaining temperatures are the averages of two experiments. A carrot decoction was made by steaming 500 gm. of peeled and finely chopped carrots for an hour in 1,000 c. c. of distilled water. Twenty gm. of agar was then added to 1,000 c. c. of this decoction. The fungus was grown in 200 c. c. Erlenmeyer flasks plugged with cotton, each flask containing 40 c. c. of the medium. The diameter of the colonies was measured by means of calipers devised for the purpose.[11]

No growth had occurred at temperatures of 39° and 5° C. at the end of eight days. Thirty-nine degrees is probably near the maximum temperature for growth. Considerable growth occurred at 5° by the end of 17 days. Some growth took place at −0.5° in 37 days. No attempt was made to grow the fungus at temperatures below −0.5°. The amount of growth represented by the area of the colonies increased rapidly as the temperature rose above 5° until it reached 28°, the optimum temperature for growth as indicated by the results obtained at the end of eight days.

A decrease in the amount of growth occurred as the temperature rose above 28°. There was a large increase as the temperature rose from 5° to 14.4° at the end of 17 days and from −0.5° to 9.4° at the end of 37 days. These relations are graphically represented in Figure 2.

[10] The temperature experiments discussed in this paper were conducted in chambers described in an earlier publication. LAURITZEN, J. I., and HARTER, L. L. SPECIES OF RHIZOPUS RESPONSIBLE FOR THE DECAY OF SWEET POTATOES IN THE STORAGE HOUSE AND AT DIFFERENT TEMPERATURES IN INFECTION CHAMBERS. Jour. Agr. Research 24: 441-456, illus. 1923.

[11] LAURITZEN, J. I. INFECTION AND TEMPERATURE RELATIONS OF BLACK ROT OF SWEET POTATO IN STORAGE. Jour. Agr. Research 33: 663-676. 1926.

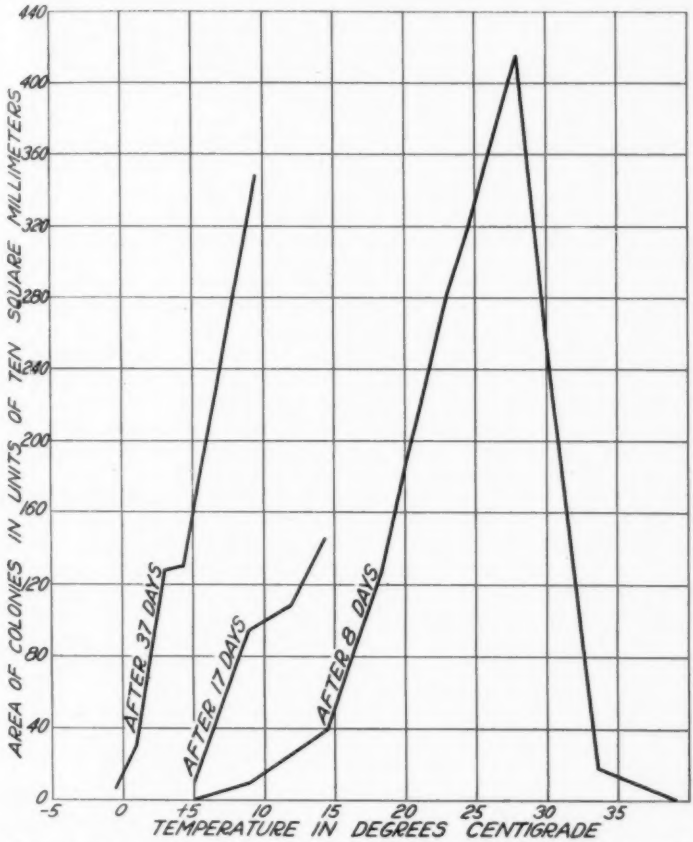

FIG. 2.—Growth of *Alternaria radicina* on carrot agar at different temperatures for 8, 17, and 37 days, respectively

TABLE 7.—*Influence of temperature on the development of black rot of carrot after different periods of time*

Temperature	Number of lesions measured after 8 days	Average area of lesions	Number of lesions measured after 15 days	Average area of lesions	Number of lesions measured after 21 days	Average area of lesions	Number of lesions measured after 35 days	Average area of lesions
°C.		*Sq. mm.*		*Sq. mm.*		*Sq. mm.*		*Sq. mm.*
34.0	2	17						
32.0	39	36	19	53				
28.0	53	132	24	504				
24.5	55	75	48	313				
23.0	52	66	30	247				
20.0	57	38	47	117				
19.0	56	44	56	155				
14.0	46	21	56	49	53	101		
11.0			50	47	49	99		
9.7	43	8			50	42	53	117
5.0	0	0			30	12	49	23
3.5					13	16	52	18

INFLUENCE OF TEMPERATURE ON INFECTION AND ON THE DEVELOPMENT OF DECAY

The results recorded in Table 7 were obtained in an experiment that had for its purpose the determination of the influence of temperature and time on the development of black rot.

The carrots were inoculated by inserting a small flake of mycelium and spores into the tissue of the root in two places on opposite sides near the top where the diameter was large. The flakes of mycelium and spores were as nearly as possible of the same size and character in each inoculation. The roots were selected in such a way that those at the different temperatures were comparable in size and shape. Thirty roots were placed at each temperature, and the average area of the lesions was computed from the total number that developed at each temperature. This number was fairly uniform except at the higher temperatures (32° and 34° C.). There was a decrease in the number of lesions at 20° and above with the lapse of time because of decay produced by *Rhizopus* sp. *Penicillium* sp., and *Bacillus carotovorus*. There was also an increased number of lesions with time at the lower temperatures because of the increased number of infections. In all cases except at 34° the number of lesions was sufficiently large to give a representative average.

The optimum temperature for the enlargement of the lesions was found to be 28° C. at the end of 8 and 15 days. As the temperature rose above this point there was a marked decrease in the average size of the lesions. The maximum temperature for infection was not determined, because at temperatures above 30° decay caused by such organisms as *Rhizopus* sp. and *Penicillium* sp. was rapid. Judging by the drop in the size of the lesions at temperatures above 28° the maximum temperature for infection is not much higher than 34°. As the temperature fell below the optimum, the size of the lesions decreased rapidly to a minimum at a temperature between 5° and 9.7° at the end of 8 days, 5° at the end of 21 days, and 3.5° at the end of 35 days. At the end of 15 days no measurements were made below 11°.

The relation of temperature to the enlargement of lesions after different periods of time is shown in Figure 3. There is a sag in the curve made from measurements taken at the end of eight days. This sag tends to straighten out during the successive periods, a fact which seems to be due in part to a proportionately more rapid enlargement of the lesions with the lapse of time at the more favorable temperatures than at the border temperatures. This relation is illustrated in Figure 4. The same relation was found to exist in connection with the study of the influence of temperature and time on the decay of sweet potato by *Rhizopus tritici* Saito;[12] in fact, it was shown more clearly because more comparable intervals of time were selected and the experiments included a greater number of periods.

This behavior may be partially explained on the basis of the differential enlargement of the lesions. Because of the influence of temperature, there is a progressively augmented differentiation of the areas exposed to the action of the fungus with the lapse of time.[13]

[12] LAURITZEN, J. I., and HARTER, L. L. THE INFLUENCE OF TEMPERATURE ON THE INFECTION AND DECAY OF SWEET POTATOES BY DIFFERENT SPECIES OF RHIZOPUS. Jour. Agr. Research 30: 793-810, fig. 9. 1925.

[13] LAURITZEN, J. I. INFECTION AND TEMPERATURE RELATIONS OF BLACK ROT OF SWEET POTATO IN STORAGE. Jour. Agr. Research 33: 663-676. 1926.

Hence not only does the rate of enlargement of the lesions as measured by their areas increase with the lapse of time, but this rate is augmented with the rise in temperature from the minimum to the optimum. As the temperature rises above the optimum the process is reversed and the rate decreases proportionately with the rise in temperature and the lapse of time.

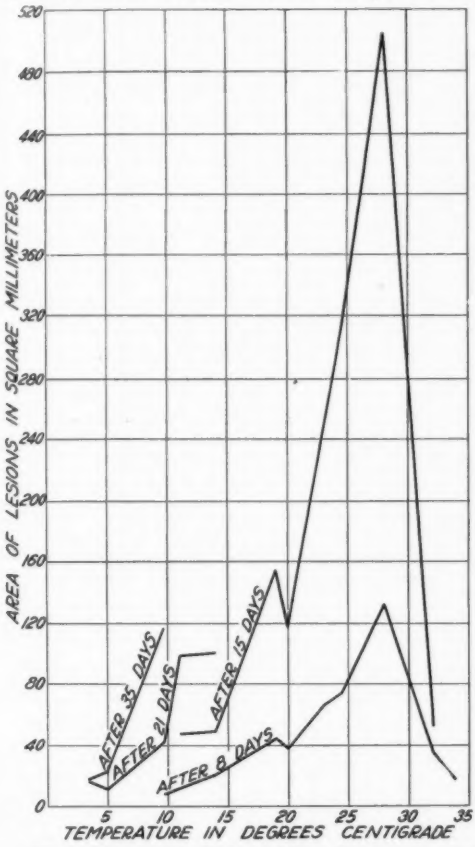

FIG. 3.—Enlargement of lesions with rise in temperature after 8, 15, 21, and 35 days, respectively

Infection of carrots by *Alternaria radicina* has occurred at a temperature as low as −0.6° C. (Table 8) in 43 days, but considerably more decay occurred at 0.5° C. in the same time. It will be seen from the results recorded in Table 8 that it is not possible to store carrots at a temperature beyond the range of infection without exposing them to the danger of freezing. All that can be done if the disease is present is to retard infection and the advance of decay by storing the carrots at temperatures ranging from 0° to 2°. This temperature is favorable for the storage of carrots.

TABLE 8.—*The lower temperature limits at which Alternaria radicina will infect carrots*

Temperature, ° C.	Duration of experiments, in days	Method of inoculation	Number of carrots used	Number of carrots infected	Percentage of carrots infected	Degree of decay	Check (uninoculated)	
							Number of carrots used	Number of carrots infected
4.4	62	Dipping carrots in spore suspension.	129	65	50	10 to 100 per cent		
1.3	158	do	510	211	41	Lesions mostly small; occasional lesion large.	507	3
.5	43	Inserting mycelium and spores into roots by means of scalpel.	110	98	89	Lesions 1 by 5 mm. to 4 by 8 mm. diameter.		
−.6	43	do	72	51	71	Infection just started		

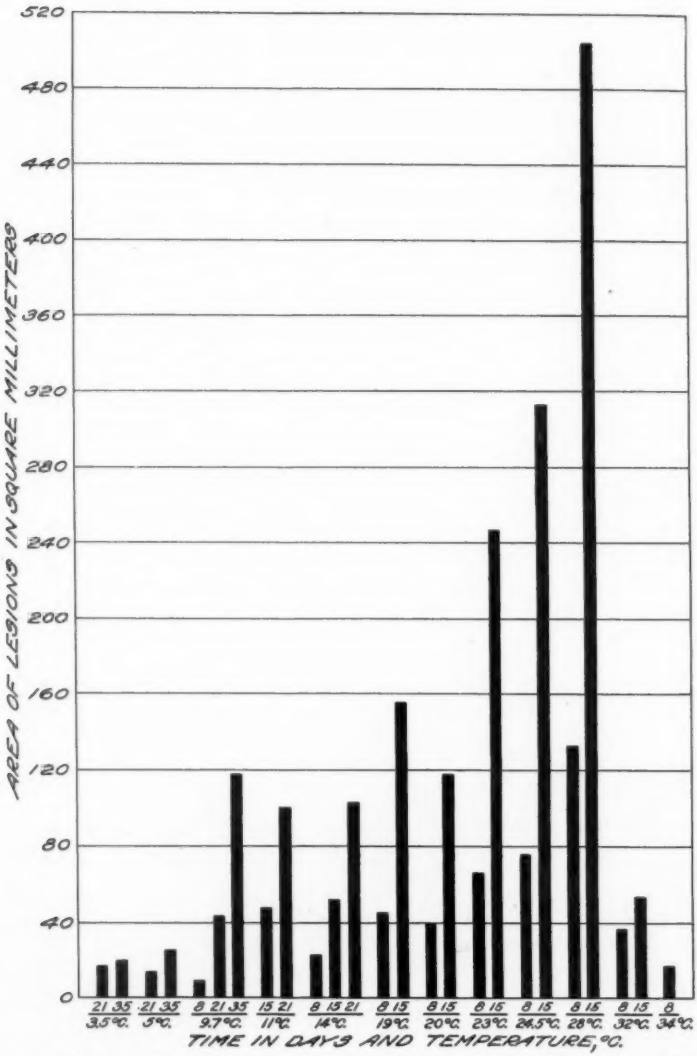

FIG. 4.—Influence of temperature and time on the enlargement of lesions caused by *Alternaria radicina*

VARIETIES AND SUSCEPTIBILITY

A study was made of the susceptibility of 17 varieties of carrots to infection by *Alternaria radicina*. Most of the varieties were used during two seasons.

The seed of the following varieties was obtained from a commercial firm in Paris, France: Jaune obtuse du Doubs, Blanche à collet vert (hors terre), Blanche lisse demi-longue, Rouge demi-longue de Danvers, Rouge longue de Saint-Valery, Rouge demi-longue de Chantenay, Rouge demi-courte de Guérande, Rouge demi-longue d'Amsterdam, Rouge à forcer Parisienne, and Rouge demi-longue Nantaise. The seed of the following varieties was obtained from a firm in Boston, Mass.: Carter's Nantes, Carter's Early Market, Carter's Red Elephant, Carter's Scarlet Perfection, Carter's Long Forcing, and Carter's Summer Favorite. The seed of Danver's Half Long was procured from a firm in Washington, D. C.

The carrots were grown at the Government experiment farm at Rosslyn, Va., on soil of uniform character and suitable for carrots. The different varieties were planted at the same time and were harvested and stored under the same conditions. Medium-sized roots for the particular variety were selected in each instance. In one experiment the carrots were washed in tap water and allowed to dry under laboratory conditions. A small flake of mycelium and spores was then inserted in the root tissue on one side near the top of the carrot by the use of a small pair of forceps. The quantity of mycelium and spores was as nearly as possible the same in each inoculation. Immediately after treatment the carrots were stored in wire baskets (12 by 12 inches) at a temperature of 13° C. in a room provided with air exchange.

TABLE 9.—*Susceptibility of 12 varieties of carrot to attack by Alternaria radicina when roots were inoculated by insertion of mycelium and spores*

Variety	Number of carrots inoculated	Number of carrots infected	Percentage of carrots infected	Average diameter of lesions in millimeters
Rouge demi-longue de Danvers	39	39	100	6.9
Carter's Nantes	39	38	97	7.1
Rouge longue de Saint-Valery	39	36	92	7.0
Rouge demi-longue Parisienne	40	40	100	7.9
Rouge demi-courte de Guérande	40	40	100	4.6
Rouge demi-longue de Chantenay	40	38	95	5.7
Carter's Long Forcing	38	37	97	6.5
Carter's Scarlet Perfection	41	40	97	6.3
Rouge demi-longue Nantaise	37	37	100	8.1
Carter's Early Market	40	40	100	8.9
Rouge demi-longue d'Amsterdam	40	35	88	7.0
Carter's Red Elephant	41	41	100	9.6

The results recorded in Table 9 were obtained after 11 days. There was very little difference either in the percentage of infection or the average diameter of the lesions in the 12 varieties used. Rouge demi-longue d'Amsterdam showed the lowest percentage of infection but not the smallest average diameter of the lesions. This method provides a severe test of pathogenicity, first because it eliminates any resistance that may be offered by the skin of the roots, and, second, because it provides for a large quantity of inoculum at the

point of inoculation. An effort was therefore made to determine the susceptibility of a number of varieties under conditions of infection that simulate more nearly the conditions that obtain in storage (except where infection occurs through the tops).

Table 10 contains the results of experiments conducted during two seasons. In each group of experiments the carrots were carefully washed to avoid wounding, dried, and inoculated by dipping in a spore suspension of the pathogene. In 1924 they were stored at a temperature of 13° C. and a relative humidity ranging from 75 to 90 per cent; in 1925 they were stored at a temperature of 10° and a relative humidity ranging from 88 to 96 per cent.

TABLE 10.—*Susceptibility of 17 varieties of carrot to attack by Alternaria radicina when the roots were inoculated by dipping in a spore suspension*

Variety	1924			1925			Total percentage of carrots infected
	Number of carrots used	Number of carrots infected	Percentage of carrots infected	Number of carrots used	Number of carrots infected	Percentage of carrots infected	
Blanche à collet vert (hors terre)				24	1	4.2	4.2
Blanche lisse demi-longue				18	2	11.1	11.1
Carter's Early Market	43	5	11.6	44	3	6.8	9.2
Carter's Long Forcing	47	3	6.4	117	0	0	1.8
Carter's Nantes	45	0	0	70	5	7.1	4.3
Carter's Red Elephant	43	3	7.0				7.0
Carter's Scarlet Perfection	47	6	12.8	40	2	5.0	9.2
Carter's Summer Favorite				42	10	23.8	23.8
Danver's Half Long	44	1	2.3	46	1	2.2	2.2
Rouge demi-longue de Danvers	44	3	6.8	26	2	7.7	7.1
Jaune obtuse du Doubs				25	1	4.0	4.0
Rouge à forcer Parisienne	45	15	33.3	45	11	24.4	28.9
Rouge demi-courte de Guérande	44	2	4.5	35	0	0	2.5
Rouge demi-longue d'Amsterdam	43	1	2.3	54	2	3.7	3.1
Rouge demi-longue de Chantenay	46	3	6.5	34	5	14.7	10.0
Rouge demi-longue Nantaise				89	6	6.7	6.7
Rouge longue de Saint Valery	45	0	0				0

All varieties proved to be susceptible except Rouge longue de Saint Valery, which, however, was used in only one year. In the case of three other varieties there was no infection in one or the other of the years, and it is therefore possible that this variety might also have become infected if it had been used in another trial. It was shown (Table 9) that *Alternaria radicina* is capable of infecting this variety when it is inoculated by inserting mycelium and spores into the tissue, and the quantity of decay was as great as in most of the other varieties.

There is some variation in the percentage of roots infected, but for the most part these differences lie within the limits of experimental error.

There are two outstanding cases of susceptibility, Rouge à forcer Parisienne and Carters' Summer Favorite. In the case of the former the percentage of infection was large both in 1924 and 1925. There is a possible explanation for susceptibility in this instance. Rouge à forcer Parisienne is a short stubby carrot which grows very rapidly. In consequence, abundant growth cracks develop in the roots, and although most of these heal over the healing is imperfect, leaving areas unprotected by the skin tissue. It is true that Rouge demi-courte de Guérande is also nearly always growth-cracked and does

not show a marked susceptibility to infection, but the cracking seems to heal more perfectly.

Carter's Summer Favorite, judging by one trial only, seems particularly susceptible. More work will be done on this variety.

It is important to note that Danver's Half Long, America's greatest commercial variety, shows a consistently low percentage of infection. Rouge demi-longue de Danvers, which is supposed to be the same variety, shows consistently a higher percentage of infection. Whether or not we are dealing here with different strains, is not known. It is known, however, that there is considerable variation [14] in Danver's Half Long in the size and shape of the roots and that the roots from French seed have been consistently larger than those from American seed. In any case Danver's Half Long, whether of American or French origin, ranks with the less susceptible varieties.

DISCUSSION AND SUMMARY

Carrot roots free from black rot and from contamination with the pathogene do not become infected when stored in a house which has not been contaminated by the previous storage of black-rot carrots. It would seem, therefore, that the disease has its origin in the field.

Carrot foliage inoculated with a spore suspension of *Alternaria radicina* became infected with a disease which very closely resembles carrot blight. Roots from plants whose foliage was inoculated showed no evidence of infection at harvest time (early November), but showed heavy infection at the termination of the storage period (April and May). These results point to a possible connection between foliage infection and root infection, but the negative results obtained from attempts to find the foliage disease under field conditions tend to discredit this view.

A larger number of infections from foliage inoculation occur at the sides of roots than at the crown, showing that it is not necessary for the pathogene to pass directly through the foliage to the roots. It would seem that the infections on the sides of the roots at least were produced by contamination with the pathogene from one of the following sources: (1) From the washing of spores from the foliage to the soil and roots; (2) from contact with foliage at harvest time, and (3) from the soil before and at the time of digging. Since *Alternaria radicina* is a vigorous saprophyte and can live indefinitely on dead organic matter, it would appear reasonable to believe that it might live in the soil, especially if decaying carrot roots and foliage were present. The roots could thus become contaminated through the soil and in turn infected during storage. This conception would account for the black rot of the roots in storage in the absence of the foliage disease.

Alternaria radicina is capable of infecting carrot roots through the uninjured skin. Such infection occurs very slowly, penetrating only a few cells deep. The mycelium sometimes surrounds the cytoplasm and at other times ramifies throughout the entire cell.

It is not necessary for the fungus to gain entrance through the uninjured skin; it can enter readily through old wounds, rootlets, and through fresh wounds. Old wounds are abundant in all stored

[14] VILMORIN-ANDRIEUX ET COMPAGNIE. THE VEGETABLE GARDEN; ILLUSTRATIONS, DESCRIPTIONS, AND CULTURE OF THE GARDEN VEGETABLES OF COLD AND TEMPERATE CLIMATES. English ed. pub. under the direction of W. Robinson. Ed. 3. p. 197-198. illus. London. 1920.

carrots, for it is impossible to harvest and store them without some wounding. Fresh wounding increases the opportunity for infection, the worse it is the greater the infection.

Temperature has little effect on the number of infections if sufficient time is allowed to permit of the maximum infection, except at the border temperatures.

Alternaria radicina will grow on carrot agar at temperatures ranging from −0.5° to 33.6° C. There was no growth at 39° in 8 days, but there was considerable growth at −0.5° in 37 days. Growth might have occurred at temperatures between 33.6° and 39° or below −0.5° had these temperatures been employed.

The optimum temperature was found to be 28° C. The decrease in the rate of growth as represented by the area of the colonies was rapid as the temperature rose above or fell below this point.

The temperature range for infection of carrots by *Alternaria radicina* extends from −0.6° to 34° C. This range is slightly wider than that for growth of the fungus, but this fact can be explained on the basis of the temperatures employed in the two instances. It is impracticable to determine the upper temperature limit of infection because carrots decay rapidly at the higher temperatures from the attack of such fungi as *Rhizopus sp.* and *Penicillium sp.* It is possible that infection might have been obtained at temperatures below −0.6° had these been employed, but a temperature even as low as −0.6° is too low for the practical storage of carrots. The best that can be done if the black-rot disease is present is to store the carrots at temperatures of from 0° to 2° C. and thus reduce the amount of infection and decay to a minimum.

The optimum temperature for infection and decay of carrots by *Alternaria radicina* is about 28° C. as shown by the results both after 8 and after 15 days. This optimum is identical with the optimum for growth of the pathogene. It is not thought, however, that the optima are as definite as these data would indicate. It is expected that they would vary somewhat if slightly different temperatures were employed.

There is a rapid decrease in the rate of enlargement of the lesions as the temperature is raised above or lowered below 28° C., particularly when it is raised above. There is a lag in the rate of enlargement of the lesions and in the number of infections in the early stages of infection and decay at temperatures below 19°, but the tendency is for this lag to be recovered with time.

The rate of growth of the fungus as represented by the area of the colonies in carrot agar is much greater at all temperatures than the rate of enlargement of the area of lesions. This fact is well illustrated in Figures 3 and 4 by the curves drawn from data obtained at the end of eight days.

Alternaria radicina has been shown to be capable of infecting 17 varieties of carrots. There is little difference in the number of infections or degree of decay as measured by the increase in the diameter of the lesions in 12 varieties when the roots are inoculated by inserting into them a small flake of mycelium and spores and storing them under the same conditions.

When carrots were inoculated by being dipped in a spore suspension, the Carter's Summer Favorite variety showed a marked susceptibility in the one experiment in which it is used. Rouge à forcer Parisienne

was the most pronouncedly susceptible variety. The susceptibility of this variety was consistently high during the two seasons in which it was used. Danver's Half Long, whether the seed was obtained in the United States or from France, was one of the least susceptible of the varieties. When the roots of Rouge longue de Saint Valery were dipped in a spore suspension this variety showed no infection in the one trial in which it was used. This fact does not prove its immunity. Three other varieties showed an absence of infection in one experiment and the presence of infection in another. Rouge longue de Saint Valery did become infected when inoculated by inserting a flake of mycelium in the roots.

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THE RELATION OF SEASONAL FACTORS TO QUALITY IN SWEET CORN[1]

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INTRODUCTION

In the course of studies designed to throw light upon the factors concerned with the quality of sweet corn grown for canning purposes, the results of which have been reported in part in an earlier paper (*3*),[2] the degree of maturity of the corn at the time of harvesting was found to be of prime importance. Since, however, the rate of coming to maturity is known to be affected by seasonal conditions, and since in the earlier experiments corn was studied from plantings made in the early spring only, it seemed desirable to determine to what extent quality in sweet corn is affected by the season during which it comes to canning maturity.

Accordingly, in the spring of 1924 plans were laid for a series of plantings to be made at intervals throughout the spring and summer, and both field and laboratory studies to be made of the corn derived from these plots. In the present paper the details of these experiments will be set forth and the results of the work discussed.

PLAN OF WORK

Two varieties—Golden Bantam, representing the early corns, and Stowell's Evergreen, representing the late—were selected for the experiments.

The ground chosen for the experimental plots was located at Arlington Experiment Farm, on the Virginia side of the Potomac River near Washington, in that portion known as the "flats," which was formed some years ago by hydraulic fill from the river channel. In contour the land was nearly level. The soil was a deep, rich loam provided with tile subsurface drainage.

Beginning at the earliest feasible date, it was planned to make plantings of each variety at intervals of 10 days throughout the season, or for a period sufficiently long to be sure that the entire growing season would be utilized. Unfavorable seasonal conditions and other factors interfered to some extent with the working out of this plan, but in all 13 plantings were made of Golden Bantam and 12 plantings of Stowell's Evergreen. The actual planting dates were: April 28, May 5, 10, 23, and 31, June 7, 17, and 27, July 9, 19, and 28, and August 7, and 19.

The seed was well selected and was purchased in sufficient quantity to make possible the seeding of all plots from the same lots of seed.

The seed was drilled in by hand machine and the seeding made purposely heavy so as to assure a good stand. When the plants were

[1] Received for publication June 19, 1926; issued December, 1926.

[2] Reference is made by number (italic) to "Literature cited," p. 1072.

sufficiently large each plot was thinned, leaving vigorous plants spaced at about 9 inches in the row in the case of Golden Bantam and from 14 to 16 inches in the case of Stowell's Evergreen.

Standard cultural practices were used throughout and all plots received like treatment.

Field records were kept of the dates when tassels were first observed in the various plots and of the time and rate at which the silking occurred, tags of different colors marked with the proper dates being attached daily to the plants showing new silks, as in previous experiments.

Considering the day on which the silks of individual ears first appeared as the starting point from which to calculate the age of the corn, samples were taken when the corn was five days old and at intervals of five days thereafter throughout the entire period of development. Upon these samples determinations were made of the weight of the whole ear, husk, cob, and cut corn, and from each lot at these various stages samples of the cut corn were taken for chemical analysis. Beginning with corn at the 10-day stage, tests were made at 5-day intervals thereafter to determine the degree of toughness of the kernels as measured by their resistance to puncture; and, beginning at the 15-day stage, practical canning tests were performed at 5-day intervals on corn from each of the plantings until it was well past canning maturity. In this way it was possible to follow through the entire history of each plot of corn; to study the relation of seasonal conditions to the vegetative activities of the plant; to observe the rate at which maturity progressed; to ascertain the nature and degree of chemical transformations occurring within the grain; and, finally, to determine the effect of these various factors on the quality of the canned product.

SEASONAL DATA

The meteorological data for the period April 16 to November 30, inclusive, are given in some detail in Figure 1.

This chart is self-explanatory except in two particulars—the curve for mean daily temperature is based upon hourly readings throughout the entire period, the combined records showing the actual temperature conditions under which the corn was grown and studied; the other exception is in respect to the sunshine and cloudiness records. The height of the daily columns is here determined by the number of hours of possible sunshine, the variable width of the band formed by these daily columns corresponding to the varying day lengths as the season advanced.

Particular attention is called to the curve showing the daily mean temperature as compared with the normal mean for the same period. It is noted that during the early spring, that is, during the latter half of April and the first week of May, the temperature did not vary much from normal. The latter two-thirds of May and the first half of June were abnormally cool, the maximum temperature frequently falling some distance below the normal mean for that period. From the middle of June to the first of September the average temperature did not vary much from normal, though for a few days in the middle of August it remained somewhat below normal, and the month closed with a short hot period which reached its highest temperature

on the 31st. With the beginning of September there was an abrupt change, the temperature dropping considerably below normal and remaining abnormally cool for almost the entire month. October showed the usual fluctuations. Several light frosts were recorded during the month, but the first killing frost occurred on the night of the 21st. The first half of November was unusually warm, with occasional sharp drops in temperature. On the night of the 16th there was a hard freeze, and for several days the temperature was considerably below normal. For the last third of the month about average temperature conditions prevailed.

The season was a particularly favorable one for observing the effect of variations in rainfall on the development and maturing of sweet corn, as during this period everything from flood to prolonged drought was encountered. Immediately after the third planting was made heavy rains up the valley of the Potomac forced the river out of its bounds, and for one or two days those plantings which had been made, as well as the adjacent land where later plantings were to be made, were under water. The remainder of May was abnormally wet. The rainfall for June was a little below normal but was fairly well distributed. With the exception of one abundant rain about the 8th of the month, July was practically rainless,

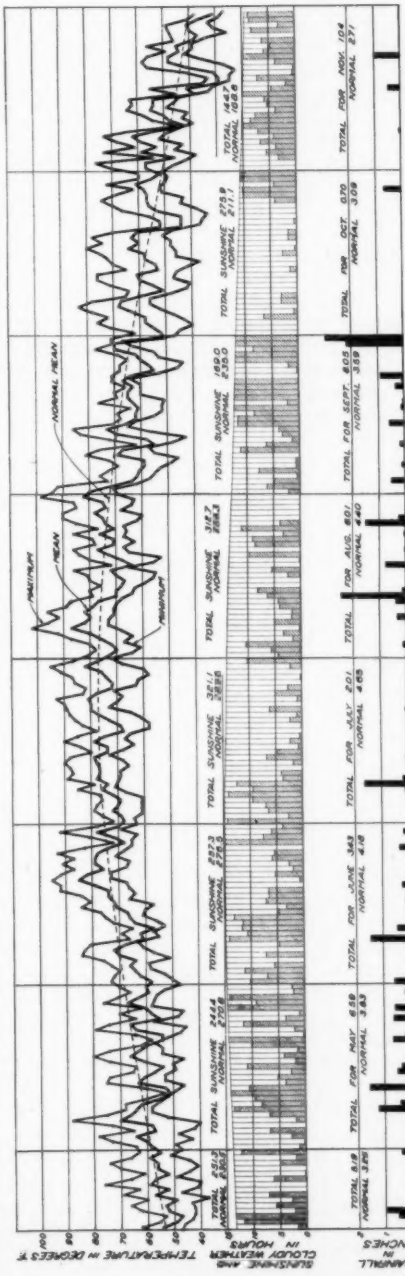

FIG. 1.—Meteorological data for the season of 1924 at Arlington Experiment Farm, Rosslyn, Va.

the total rainfall for the month being less than one-half the normal quantity; and it was not until about the 12th of August that sufficient rain fell to be of material benefit to the crop. With the breaking of the drought, the remainder of August had about the normal amount of rain. The precipitation during September was well distributed and about normal for the month, up to the last two days, when there was a downpour totaling somewhat over 5 inches. October was entirely rainless except for the 28th, when 0.7 inch of rain was recorded. November received about 60 per cent of its normal precipitation.

Brief notice should be taken of the sunshine record for this period. During May and June there was a small deficiency in sunshine. July, which normally has a slightly higher percentage of sunshine than any other month, during this season had an excess of a little over 31 hours. August had a considerable excess, amounting to over 54 hours, whereas September had a very considerable deficiency. The amount of sunshine for October was far above normal, concomitant with the rainless period. The data for November show a deficiency.

The importance of these various seasonal factors as affecting sweet corn will be shown as the results of this study are set forth.

TIME AND RATE OF SILKING

The time of planting has a very important bearing on the development of the sweet-corn crop. It has been a matter of common observation that very early planting does not necessarily result in a particularly early crop, and even in those regions where the growing season is short and frost hazards are encountered in the early fall the grower has some leeway as to the time when the planting may be done and still have the corn come to canning maturity. In other words, experience has shown that a difference of several days to a week in the time of planting in the early spring makes no noticeable difference in the time at which the corn comes to harvest.[3]

In the present experiments an opportunity was offered to study this matter rather closely, and the results of these observations are illustrated in Figures 2 and 3. No graphs are included in these figures for the last planting of each variety, since these plantings had not reached the silking stage when the crop was killed by frost. The individual graphs are so placed as to show by the ordinates the relative positions of the different plantings with respect to planting dates, and by the abscissas the period of time during which silking occurred. The height of the columns for different days in the individual graphs shows the percentage of the total silks that made their appearance on individual days.

In a chart constructed in this way the graphs for the different plantings, provided no seasonal or other factors modified the rate at which crop growth proceeded, would show the peak of silking at a definite interval from the planting date, and a line drawn through the points on the chart representing these dates would be a straight line. Such a line is represented in Figures 2 and 3. The position of this line with respect to the graphs in each of these figures was determined by taking as the interval between planting and silking the shortest

[3] In this connection, reference is made to the experimental work on field corns by Morrow and Hunt (8), Foster (4), Morrow and Bone (9), and Alberts (1).

period actually observed in the tests. In the case of Golden Bantam this period was 55 days, and in the Stowell's Evergreen, 63 days.

In the case of Golden Bantam it is seen that the first planting required about 25 days longer to arrive at the peak of silking than did the seventh and eighth. The second and third plots which were planted five days apart arrived at the peak of silking on the same day, and required 22 days more than the seventh and eighth plots to arrive at the same stage of development. In later plantings the interval from planting to silking was gradually reduced until the shortest was reached in the seventh and eighth plots. In the succeeding plantings there was a gradual lengthening of the period again, which was particularly marked in the last planting.

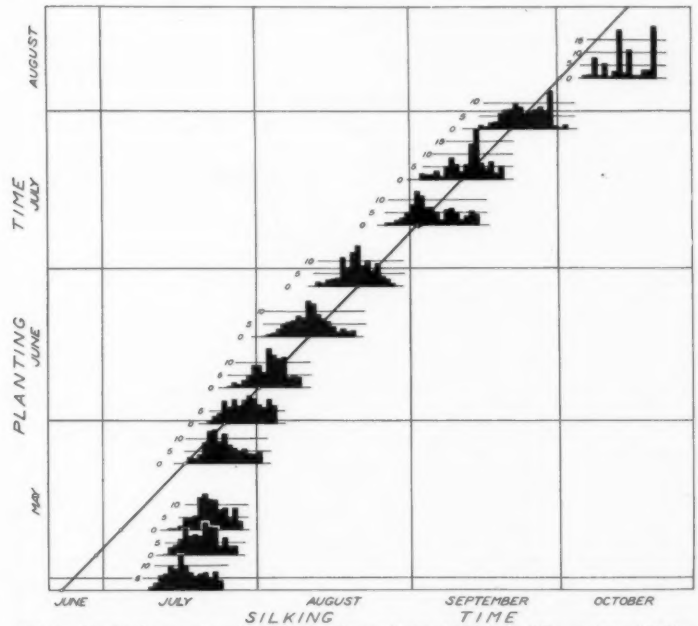

FIG. 2.—Effects of seasonal conditions on the time and rate at which the different plots of Golden Bantam sweet corn came into silking

In the case of Stowell's Evergreen the picture is entirely similar, though the variations from the minimum period are even more pronounced than has been observed in the case of Golden Bantam. Here the interval between planting and midsilking, in the case of the first planting, was about 30 days longer than that required by the seventh and eighth plantings to reach a comparable stage of development, and a very considerable lengthening of the period was observed in the last planting.

The experimental findings, therefore, accord with practical observations in showing that very little is to be gained with respect to earliness of the sweet-corn crop by very early planting, and that the grower desiring to have a succession of harvests at more or less defi-

nite intervals will need to time his early spring plantings at considerably longer intervals than with the late spring plantings.

The factors responsible for the variations here observed and the further significance of these variations as affecting the harvest will be discussed at greater length further on in this paper.

VEGETATIVE CONDITION OF CROP

The effect of seasonal conditions upon the development of the different plots of corn was very striking. Judged purely by appearance, one would have considered the various plantings, particularly of Stowell's Evergreen, as made up of a number of different varieties

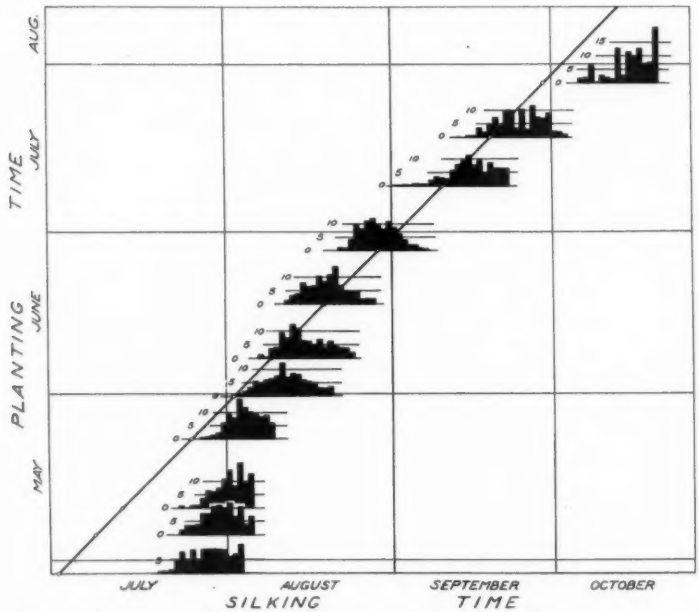

FIG. 3.—Effects of seasonal conditions on the time and rate at which the different plots of Stowell's Evergreen sweet corn came into silking

In those plots whose normal vegetative growth period fell within the season of drought the plants were stunted, and in those cases in which silking occurred during this period the ears were particularly affected. Often ears that from external appearance were judged to be normal on husking would exhibit large full-grown cobs with only scattering kernels or almost none at all. In these cases difficulty was encountered in getting sufficient corn to meet sampling needs. From the standpoint of yield, such corn was practically a total failure.

Figure 4 gives some idea of the effect of seasonal conditions on the vigor of the plants in the different plots of Stowell's Evergreen. The data are based upon the averages of numerous measurements made upon the mature stalks in the different plots, with the excep-

tion of the last two in which a killing frost prevented the development of the plants to full vegetative maturity.

Attention is called particularly to the height of the corn and the position of the ears in plots 4, 5, and 6 as indicated in the chart. The corn in these plots passed a considerable portion of their actively vegetative periods during the season of drought recorded as between the middle of July and the 12th of August.

It is seen from this and the preceding figures that the quantity and distribution of the rainfall, as well as the temperature conditions prevailing during the growing period, have a very important bearing on the vegetative development of the sweet-corn plant.

YIELDS

No attempt was made in the present study to determine the effect of seasonal conditions on total yields of corn from the various plots, the conditions under which the experiments were conducted not making it feasible to secure such records. In general, the vegetative condition of a field of corn is a fairly good index of yields, and reference to Figure 4 will give some notion of relative yields from the different plots in the present case. It should be borne in mind, however, that in point of time the development of the ear lags somewhat behind the vertical growth of the corn plant, and factors affecting the physical condition of the corn plant would be reflected in the ear at a slightly later time than in the stalk. Field observations showed that the yield from the third plot was relatively less than the graph for that planting would indicate and somewhat more than would be inferred from the graph for the sixth plot.

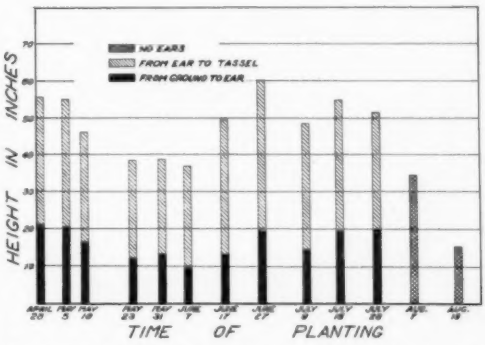

FIG. 4.—Effect of seasonal conditions on the vegetative development of the different plots of Stowell's Evergreen sweet corn. The heavy black portions of the individual graphs give the distance from the ground to the base of the ear, and the crosshatched portion the distance from the ear node to the base of the tassel

As in previous studies (*3*), records were kept of the rate of development of the ears and the proportion of husk, cob, and cut corn in the ears at different stages of maturity. The data secured are presented in Table 1. Too close analysis of the figures in this table should not be made, as the number of ears available for individual tests were too few for accurate determination of averages. Irregularities in the series of figures indicating the progress of development of the different elements of the ear are occasionally observed in the table, which are due in part to this element of error and in part to the effect of drought on some of the corn, which affected the percentage yields. The full effect of drought, however, is not shown, since abnormal ears, as far as possible, were excluded from the tests.

TABLE 1.—*Rate of development of the sweet-corn ear and the changes occurring in the proportion of husk, cob, and cut corn during growth of Golden Bantam and Stowell's Evergreen varieties, planted at intervals throughout the season of 1924 at Arlington Experiment Farm, Rosslyn, Va.*

Planting	Date of planting, 1924	Golden Bantam								Stowell's Evergreen							
		Date of sampling	Age in days	Number of ears taken	Average weight of ears	Average weight husked ears	Average weight of cut corn per ear	Per cent of husk	Per cent of cob	Per cent of cut corn	Date of sampling	Age in days	Number of ears taken	Average weight of ears	Average weight husked ears	Average weight of cut corn per ear	Per cent of husk	Per cent of cob	Per cent of cut corn
					Grams	*Grams*	*Grams*							*Grams*	*Grams*	*Grams*			
1	Apr. 28	July 16	5	20	79.8	25.0	12.3	68.7	15.8	15.5	July 30	5	22	128.4	50.4	19.8	60.8	23.8	15.4
		July 22	10	15	129.1	68.6	21.5	46.9	36.5	16.6	Aug. 1	10	11	257.7	146.3	33.1	43.2	44.0	12.8
		July 29	15	13	164.6	97.3	38.7	40.9	35.5	23.6	Aug. 7	15	7	264.2	167.9	73.5	36.6	35.6	27.8
		Aug. 4	20	10	182.0	133.0	80.0	27.0	29.1	43.9	Aug. 15	20	7	321.4	223.5	139.2	30.5	26.2	43.3
		Aug. 14	25	10	158.0	109.5	68.5	30.8	25.9	43.3	Aug. 23	25	6	384.1	262.5	173.3	31.7	23.2	45.1
		Aug. 16	30	12	179.6	137.9	96.2	23.2	23.2	53.6	Aug. 30	30	5	398.0	294.0	211.0	26.2	20.8	53.0
2	May 5	July 21	5	21	75.4	23.3	9.8	69.2	17.8	13.0	July 31	5	15	151.6	54.0	18.6	64.5	23.3	12.2
		July 28	10	16	105.2	59.5	21.3	43.5	36.2	20.3	Aug. 4	10	10	215.5	133.5	43.9	38.2	41.5	20.3
		Aug. 1	15	15	127.6	81.3	29.4	36.4	40.6	23.0	Aug. 8	15	12	264.1	165.0	64.5	37.6	38.0	24.4
		Aug. 11	20	6	221.6	144.1	88.3	34.9	25.2	39.9	Aug. 18	20	6	350.0	228.3	130.0	34.8	28.1	37.1
			25								Aug. 26	25	6	416.6	297.5	194.1	28.6	24.8	46.6
		Aug. 22	30	5	167.0	118.0	78.0	29.4	23.9	46.7	Sept. 3	30	6	361.6	262.5	190.8	27.5	19.8	52.7
3	May 10	July 23	5	16	92.2	29.5	13.3	68.1	17.5	14.4	Aug. 1	5	13	147.3	55.0	17.5	62.7	25.4	11.9
		July 30	10	20	116.0	57.3	21.0	50.6	31.3	18.1	Aug. 15	10	12	226.6	100.8	23.7	55.6	34.0	10.4
		Aug. 1	15	15	158.0	82.0	24.2	48.2	36.4	15.4	Aug. 12	15	10	271.0	161.0	70.5	40.7	33.3	26.0
		Aug. 8	20	11	174.5	113.1	62.1	35.2	29.2	35.6	Aug. 18	20	7	385.6	244.2	143.5	36.7	26.1	37.2
		Aug. 21	25	4	160.0	111.2	71.2	30.5	25.0	44.5	Aug. 26	25	7	403.6	300.0	200.0	25.6	24.8	49.6
		Aug. 23	30	6	196.6	136.6	98.3	30.5	19.5	50.0	Sept. 3	30	6	354.1	275.0	191.6	22.4	23.5	54.1
4	May 23	July 23	5	20	72.5	25.7	11.4	64.6	19.7	15.7	Aug. 4	5	15	125.3	49.0	18.2	61.0	24.5	14.5
		July 30	10	19	110.8	59.3	22.7	46.5	33.0	20.5	Aug. 8	10	12	230.4	116.6	30.0	49.4	37.6	13.0
		Aug. 5	15	12	152.9	96.8	41.2	36.8	36.3	26.9	Aug. 15	15	10	307.0	195.0	78.0	36.5	38.1	25.4
		Aug. 8	20	10	157.0	104.5	60.0	33.5	28.3	38.2	Aug. 22	20	7	344.3	219.3	127.1	36.4	26.7	36.9
		Aug. 22	25	6	181.6	123.3	77.5	32.2	25.2	42.6	Sept. 2	25	6	208.3	145.0	88.3	30.4	27.2	42.4
		Aug. 25	30	6	176.6	143.3	105.8	18.9	21.2	59.9	Sept. 4	30	5	364.0	266.0	183.0	27.0	22.8	50.2
5	May 31	July 28	5	22	66.3	20.0	8.9	69.9	16.7	13.4	Aug. 8	5	10	115.5	44.5	16.8	61.5	24.0	14.5
		Aug. 3	10	15	108.2	53.5	18.4	50.6	32.4	17.0	Aug. 14	10	14	189.2	101.7	31.8	46.4	36.9	16.7
		Aug. 9	15	10	154.5	89.9	42.5	41.8	30.7	27.5	Aug. 21	15	10	270.0	119.0	48.0	38.3	44.0	17.7
		Aug. 20	20	9	175.0	109.3	63.8	37.5	26.0	36.5	Aug. 28	20	7	358.6	230.5	120.0	35.8	30.8	33.4
		Aug. 28	25	4	166.2	122.5	82.5	26.4	24.0	49.6	Sept. 4	25	7	343.5	246.4	169.3	28.4	22.4	49.2
		Aug. 27	30	9	176.6	134.4	97.2	24.0	21.0	55.0	Sept. 11	30	6	439.1	323.3	225.0	26.5	22.3	51.2

6	June 7	Aug. 1	5	14	76.8	18.9	8.0	74.5	15.0	10.5	Aug. 12	5	13	140.0	57.2	20.0	59.2	26.6	14.2
		Aug. 8	10	11	119.5	55.4	14.0	53.7	34.6	11.7	Aug. 20	10	14	227.1	121.7	32.1	46.5	39.4	14.1
		Aug. 15	15	10	163.0	88.0	32.0	46.1	34.3	19.6	Aug. 26	15	7	337.1	205.0	75.0	39.3	38.5	22.2
		Aug. 21	20	7	170.7	108.5	82.1	36.5	15.4	48.1	Sept. 2	20	7	357.8	245.0	145.7	31.6	27.7	40.7
			25								Sept. 9	25	6	391.6	296.6	208.3	24.4	22.5	53.1
		Sept. 5	30	6	167.5	122.5	85.0	27.0	22.3	50.7	Sept. 15	30	7	264.2	188.5	105.0	28.7	31.6	39.7
7	June 17	Aug. 21	5	18	72.2	23.6	8.6	67.4	20.7	11.9	Aug. 18	5	14	136.4	46.7	17.1	65.8	21.7	12.5
		Aug. 14	10	12	117.0	51.6	20.3	56.0	26.6	17.4	Aug. 23	10	12	272.9	150.4	53.3	44.9	35.6	19.5
		Aug. 22	15	9	164.4	86.6	31.1	47.4	33.7	18.9	Aug. 29	15	7	323.5	195.6	90.0	39.6	32.6	27.8
		Aug. 29	20	7	186.4	114.3	56.5	38.8	31.0	30.2	Sept. 8	20	6	443.3	299.1	177.5	32.6	27.4	40.0
		Sept. 6	25	7	202.8	131.4	90.0	35.3	20.4	44.3	Sept. 11	25	6	415.0	333.3	231.6	19.7	24.5	55.8
		Sept. 15	30	5	214.0	157.0	111.0	26.8	21.4	51.8	Sept. 19	30	6	470.0	342.5	245.8	27.2	20.5	52.3
8	June 27	Aug. 18	5	14	62.1	15.7	6.8	74.8	14.3	10.9	Aug. 28	5	11	170.9	74.0	26.8	56.7	27.6	15.7
		Aug. 25	10	16	120.6	47.5	17.8	48.5	24.6	26.9	Sept. 4	10	11	294.5	164.0	54.5	44.4	37.1	18.5
		Sept. 2	15	7	151.4	88.5	42.9	41.6	30.1	28.3	Sept. 10	15	7	391.4	229.2	89.3	41.5	35.7	22.8
		Sept. 9	20	8	194.3	122.5	68.7	37.1	27.6	35.3	Sept. 16	20	6	428.3	268.3	140.8	37.5	29.7	32.8
		Sept. 15	25	9	180.0	115.0	72.2	36.2	23.7	40.1	Sept. 22	25	7	472.8	307.1	160.0	35.1	31.1	33.8
		Sept. 22	30	8	201.2	138.7	95.6	31.1	21.4	47.5	Sept. 27	30	6	508.3	375.0	221.6	26.3	30.1	43.6
											Sept. 27	35	• 3	453.3	321.6	235.0	29.1	19.1	51.8
9	July 9	Sept. 3	5	15	70.6	22.6	9.3	68.0	18.8	13.2	Sept. 11	5	9	114.4	35.5	15.5	69.1	17.4	13.5
		Sept. 10	10	14	111.7	46.7	16.0	58.3	27.4	14.3	Sept. 18	10	14	194.2	72.5	23.5	62.8	25.1	12.1
		Sept. 15	15	10	130.0	70.0	26.0	46.2	33.8	20.0	Oct. 1	15	10	244.0	132.0	41.0	46.0	37.2	16.8
		Sept. 26	20	8	153.7	77.5	27.5	49.7	32.5	17.8	Oct. 3	20	7	305.0	180.0	66.4	41.0	37.2	21.8
		Sept. 29	25	10	170.0	104.5	52.0	38.6	30.8	30.6	Oct. 6	25	7	315.0	176.4	70.0	44.5	33.3	22.2
		Oct. 2	30	2	200.0	137.5	87.5	31.3	25.0	43.7	Oct. 9	30	6	346.6	181.6	83.3	47.7	28.3	24.0
		Oct. 14	35	8	145.0	90.0	56.2	38.1	23.2	38.7	Oct. 11	35	4	347.5	227.5	135.0	34.6	26.6	38.8
											Oct. 17	40	6	268.3	204.1	130.8	24.0	27.3	48.7
10	July 18	Sept. 9	5	14	73.9	18.2	8.2	75.4	13.5	11.1	Sept. 22	5	15	132.6	26.3	8.3	80.3	13.5	6.2
		Sept. 15	10	14	115.0	30.0	10.7	74.0	16.7	9.3	Sept. 29	10	8	225.0	101.8	26.7	54.8	32.5	12.7
		Oct. 2	15	10	142.0	54.0	18.0	62.0	25.4	12.6	Oct. 10	15	12	245.0	102.9	26.6	58.1	31.1	10.8
		Oct. 4	20	10	157.0	67.0	24.0	57.5	27.3	15.2	Oct. 13	20	12	221.6	122.5	30.8	44.8	41.3	13.9
		Oct. 7	25	6	211.6	105.0	44.1	50.5	28.7	20.8	Oct. 16	25	9	317.7	168.8	51.6	47.0	36.8	16.2
		Oct. 9	30	8	183.1	102.5	78 1	44.1	13.3	42.6	Oct. 20	30	7	327.1	197.1	75.7	44.2	32.7	23.1
		Oct. 25	35	5	240.0	99.0	58.0	58.9	17.0	24.1	Oct. 20	35	5	330.0	202.0	95.0	38.9	32.4	28.7
		Oct. 25	40	6	215.0	121.6	75.9	43.5	21.3	35.2	Oct. 29	♭ 40							
											Nov. 8	50	5	314.0	248.0	155.0	21.1	29.6	49.3
11	July 28	Sept. 20	5	11	80.0	13.6	6.8	83.0	8.5	8.5	Nov. 8	30	10	241.0	112.0	26.0	53.7	35.6	10.7
		Sept. 26	10	7	94.2	27.1	12.5	71.3	15.4	13.3	Oct. 29	40	6	391.6	280.0	141.6	28.6	35.3	36.1
		Oct. 8	15	14	85.3	35.0	12.1	59.0	26.8	14.2									
		Oct. 11	20	14	135.0	54.6	19.2	50.5	35.3	14.2									
		Oct. 14	25	7	160.0	80.7	20.0	53.2	34.3	12.5									
		Oct. 17	30	8	146.8	80.6	42.5	45.2	25.9	28.9									
		Oct. 23	35	8	152.5	109.6	60.6	34.1	26.2	39.7									
		Oct. 30	40	7	107.1	69.3	38.5	35.4	28.6	36.0									

• Small.

♭ Records lost.

The results obtained in the first seven plantings show fairly close agreement, no outstanding variations appearing in the corn from these plots. The first significant differences are observed in the corn of the eighth planting of Stowell's Evergreen and the ninth planting of Golden Bantam. Here there is noted a distinct falling off in the yield in the corn 20 days and over in age, caused by the slower rate at which maturity progressed, and the differences are even more marked in the corn of the later plantings. For instance, in the tenth planting of Stowell's Evergreen the yield of cut corn from ears 50 days old was scarcely equal to that of the earlier planting at 30 days of age. Comparable differences are noted in the late plantings of Golden Bantam.

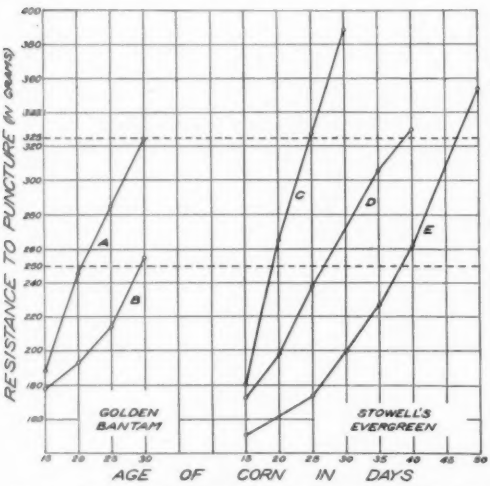

FIG. 5.—Degree of toughness of Golden Bantam and Stowell's Evergreen sweet corn at different stages of maturity, as shown by puncture tests made on samples from the different plots. Curve A, average of the first eight plantings; B, average of the ninth, tenth, and eleventh plantings; C, average of the first seven plantings; D, results from corn of the ninth planting; E, results from corn of the tenth planting

Reference to the figure giving the meteorological data will show that this falling off in yield is closely correlated with the temperature conditions prevailing during the growing season of these late plantings.

TENDERNESS

The quality of canned sweet corn is more closely associated with tenderness of the kernels than with any other property of the raw corn, and it is of interest, therefore, to observe the effect of seasonal conditions on the degree of toughness which the kernels possess.

By the use of the puncturing instrument described by the writers in an earlier paper (*3*), toughness tests were made on the corn from all the test plots at different stages of maturity, and the results of these tests are assembled in Figure 5. The ordinates show the amount of pressure, expressed in grams, required to puncture the kernels with a blunt-pointed needle constructed from No. 16 gauge brass wire, and the abscissas show the age of the corn in days when the tests were made. Because of the close agreement of results with the corn of the first eight plantings of Golden Bantam, the data for these are combined in a single curve. The results from the first seven plantings of Stowell's Evergreen, for the same reason, are similarly expressed.

It is noted that those curves showing the average results from the first plantings of both Golden Bantam and Stowell's Evergreen rise very rapidly, closely approximating straight lines, and that the curve

for Stowell's Evergreen is somewhat steeper than that for Golden Bantam. The degree of toughness reached is also considerably higher. Of particular interest, however, are the curves illustrating the findings on the corn of the later plantings. Here it is seen that the toughening process was considerably retarded, and that with succeeding late plantings, as shown in the curves for Stowell's Evergreen, the retardation became greatly marked.

In the earlier studies it was found that, taking into consideration the excessive toughness of over-mature corn, on the one hand, and too thin consistency due to immaturity, on the other, corn grading in resistance to puncture between the limits of 250 and 325 gm., as measured by this method, yielded a product of the highest quality. In these tests Golden Bantam did not exceed the upper limit for toughness in any of the plots under 30 days of age. On the other hand, the first seven plantings of Stowell's Evergreen passed through the prime canning stage, as judged by the toughness factor, at 19 to 25 days, the ninth plot at 27 to 39 days, and the tenth plot at 38 to 47 days of age.

While it is true that different varieties of sweet corn, and even different strains within the same variety, normally show unequal degrees of toughness at comparable stages of maturity, it is seen that seasonal factors also very definitely affect the tenderness of the kernels. In the present case the widest differences are noted between those plots of corn maturing during the hottest part of the season, on the one hand, and those maturing during the cooler weather of the late fall, on the other; and it would appear from this that temperature is the most important factor concerned with this phenomenon.

CHEMICAL STUDIES

The development of the corn kernel has its morphological, physiological, and chemical aspects. These are interrelated and each has an important bearing on the quality of the canned product. The complete chemical story is infinitely complex, owing to the working out of manifold vital processes, and only the gross chemical changes can be followed in the development of the kernel to maturity. However, the accumulation and transformations of the carbohydrates are so great that they are easily followed. Their significance as nutritive materials and the rôle which they play in determining quality in the canned product are of such importance that it seemed wise to undertake a rather thorough study of them in the present work.

As already stated, samples were taken for chemical analysis at 5, 10, 15, 20, 25, and 30 days from the date of silking from each of the plantings. The methods of analysis were practically the same as those used by the writers in their previous study (*3*).

MOISTURE

In the above-mentioned publication it was shown that for any variety the degree of maturity was rather closely correlated with the moisture content, the lower the moisture content the more mature the corn. From the present work it is apparent that this also holds true, regardless of the time when the plantings are made. In Table 2 are given the figures for total solids found in Golden Bantam and Stowell's Evergreen corns from each of the experimental plots, sampled at different stages of maturity.

TABLE 2.—*Percentage of total solids in Golden Bantam and Stowell's Evergreen sweet corn at different stages of maturity, from plantings made at intervals throughout the season*

GOLDEN BANTAM

Age of ears in days	Planting										
	1	2	3	4	5	6	7	8	9	10	11
	Apr. 28	May 5	May 10	May 23	May 31	June 7	June 17	June 27	July 9	July 18	July 28
5	10.62	13.11	12.02	11.83	12.56	13.41	9.93	10.51	10.36	10.54	9.56
10	12.56	13.18	13.96	13.76	11.67	13.56	11.21	10.21	10.01	9.99	10.01
15	20.67	19.99	19.78	22.28	22.51	19.81	18.64	18.59	12.59	10.68	10.77
20	30.18	33.87	31.95	32.19	29.60	28.12	29.09	26.50	15.05	13.21	12.60
25	37.31	.....	36.70	35.53	35.02	33.35	31.50	28.10	18.58	16.61	15.98
30	41.58	41.97	42.83	40.21	39.21	41.22	33.63	30.92	27.38	19.79	18.97
35	.....	.....	.....	.....	.....	.....	.....	.....	31.09	21.43	23.21
40	.....	.....	.....	.....	.....	.....	.....	.....	.....	27.56	26.46
50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	32.06
60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	34.95

STOWELL'S EVERGREEN

5	11.60	10.64	11.72	13.74	12.58	11.40	10.69	9.45	10.86	8.75	.....
10	11.28	11.72	11.43	12.78	12.54	12.60	11.56	11.04	10.23	9.12	.....
15	16.02	17.97	18.30	17.87	16.47	14.02	14.27	13.55	10.11	9.38	.....
20	21.43	20.76	21.03	24.39	20.62	22.01	20.35	17.36	11.70	10.89	.....
25	26.04	27.23	26.88	27.37	27.24	25.68	25.08	19.83	15.41	12.00	.....
30	31.36	33.95	35.22	35.32	32.33	27.35	28.39	24.33	20.50	15.26	.....
35	.....	.....	.....	.....	.....	.....	.....	29.16	23.99	18.69	.....
40	.....	.....	.....	.....	.....	.....	.....	.....	26.27	21.87	.....
50	.....	.....	.....	.....	.....	.....	.....	.....	.....	25.92	.....
60	.....	.....	.....	.....	.....	.....	.....	.....	.....	28.62	.....

It is seen that the moisture content steadily decreased during the development and maturing of the kernel. In the 5 and 10 day samples it did not vary greatly in any of the plantings, the total moisture amounting to 86 to 90 per cent. The moisture in the corn at the 15-day stage did not vary much for the first eight plantings, but the ninth, tenth, and eleventh plantings showed a marked increase resulting from the decreased rate of maturing. At the 20-day stage the first seven plantings showed only small variations, but the eighth increased considerably, and the ninth, tenth, and eleventh showed a progressive increase. At the 25 and 30 day stages the variation was not great in the first six plantings, but a progressive increase was shown in the corn of all the later plantings. These changes are best shown in Figure 6, which illustrates by curves the differences in the total solids of the kernels of the different plantings at various stages in their development.

By correlating the data on moisture in the corn with the weather records shown in Figure 1, it becomes apparent that the primary factor affecting the moisture changes in the developing ears was temperature, for all samples taken on or after September 10 showed an increase in the moisture content. The sudden change early in September from summer to late autumn temperatures, which has already been mentioned, caused a rather abrupt slowing down in the rate at which the corn matured, and the moisture content of the kernels at different stages of development was higher than that of corn of like age sampled previously. A sudden change in temperature produces a very noticeable effect in a few days.

It is noted that throughout the entire series of tests Stowell's Evergreen had a higher moisture content than Golden Bantam, being especially marked after the 15-day stage. A high moisture content seems to be a specific characteristic of Stowell's Evergreen,

and appears to be correlated with its somewhat slower rate of maturing as observed in the field. However, the writers have been led to doubt whether the difference in the moisture content of different varieties is a true measure of the differences in the rate of maturity.

The moisture content of sweet corn very greatly affects the consistency of the canned product. At the 15-day stage the corn is entirely too watery to make a satisfactory product, while at the 30-day stage it is entirely too dry. The difference in the moisture content of Stowell's Evergreen and Golden Bantam results in a difference in the consistency of the canned material from the two varieties. The 20-day Golden Bantam is of very nearly the same consistency as the 25-day Stowell's Evergreen, and from the table

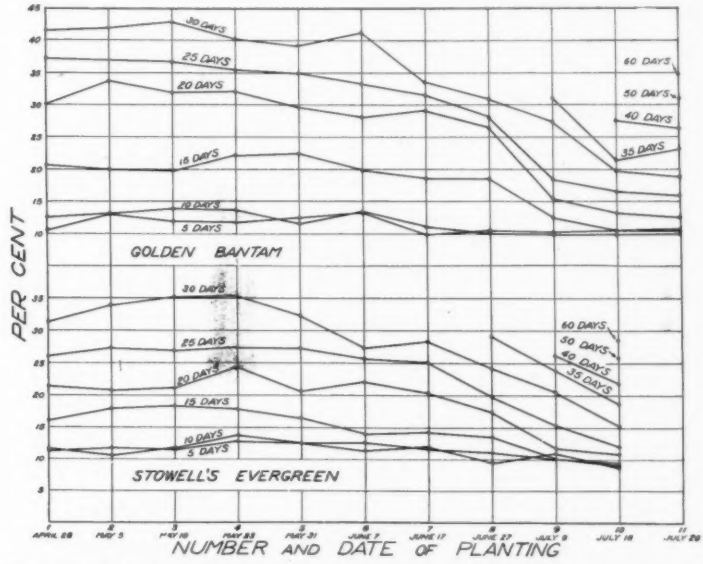

FIG. 6.—Total solids in the cut corn from ears of Golden Bantam and Stowell's Evergreen sweet corn harvested from the different plots at different stages of maturity

given above it is observed that the moisture content is very nearly the same in the two cases.

SUGARS

During the development and maturing of the sweet-corn kernel the sugar content is constantly changing. The percentage present is determined by its concentration in the cell sap and the relative proportion of cell sap to accompanying insoluble constituents. Some of the young samples have a rather high sugar content caused in part by the absence of other substances, such as starch and dextrin. The ratio of the solids to sugar is therefore important, and since the polysaccharides increase tremendously in the older corn the lower percentage of sugar in these is due in part to an increase in polysaccharides rather than to a change in concentration. The percentage of sugars found in the corn at different stages of growth in the various plantings is shown in Table 3.

TABLE 3.—*Percentage of total, reducing, and nonreducing sugars in Golden Bantam and Stowell's Evergreen sweet corn at different stages of maturity, from plantings made at intervals throughout the season*

[Sugars calculated as invert]

GOLDEN BANTAM

Age of ears in days	First planting, Apr. 28			Second planting, May 5			Third planting, May 10			Fourth planting, May 23			Fifth planting, May 31			Sixth planting, June 7			Seventh planting, June 17			Eighth planting, June 27			Ninth planting, July 9			Tenth planting, July 18			Eleventh planting, July 28		
	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing	Total	Reducing	Nonreducing
5	4.57	3.36	1.21	5.22	3.86	1.36	5.38	4.12	1.26	5.44	3.78	1.66	5.21	3.90	1.31	4.96	3.80	1.16	3.96	3.25	0.71	3.80	3.11	0.69	3.91	3.14	0.77	3.77	3.10	0.67	4.26	3.30	0.96
10	5.56	3.91	1.65	5.72	3.97	1.75	5.84	3.95	1.89	6.20	3.91	2.29	5.28	3.73	1.55	5.44	3.68	1.76	4.93	3.40	1.53	4.40	3.80	.60	4.17	3.12	1.05	4.28	3.27	1.01	4.12	3.25	.87
15	6.84	2.28	4.56	6.58	1.93	4.65	6.92	1.94	4.98	6.44	1.82	4.62	7.36	2.14	5.22	6.28	1.84	4.44	6.16	2.03	4.13	6.64	2.03	4.61	5.21	2.83	2.38	5.28	3.74	1.54	4.54	3.31	1.23
20	4.88	1.25	3.63	4.64	1.27	3.37	4.49	.89	3.60	4.56	.94	3.62	5.48	1.41	4.07	4.98	1.12	3.86	4.96	1.49	3.47	5.85	1.52	4.33	6.60	2.57	4.03	5.83	2.85	2.98	5.41	3.45	1.96
25	3.14	.66	2.48	.....	.....	.....	3.88	.80	3.08	3.64	.81	2.83	3.64	.68	2.96	3.64	.81	2.83	4.36	.91	3.45	4.72	1.22	3.50	5.14	1.33	3.81	6.44	2.57	3.87	6.93	2.66	4.27
30	2.06	.59	1.47	2.24	.68	1.56	2.96	.68	2.28	2.74	.73	2.01	2.36	.61	1.75	2.96	.70	2.26	3.54	.82	2.72	2.90	.94	1.96	3.82	1.01	2.81	5.84	1.88	3.96	6.54	2.19	4.35
35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.10	.74	2.36	5.26	1.31	3.95	6.01	1.85	4.16
40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.06	.96	3.10	4.50	1.26	3.24
50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.12	.97	2.15
60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.58	.98	1.60

STOWELL'S EVERGREEN

5	5.70	3.86	1.84	5.80	4.38	1.42	6.23	3.95	2.28	6.01	4.14	1.87	5.65	4.09	1.56	5.69	4.30	1.39	4.28	3.34	0.94	3.85	3.13	0.72	4.48	3.38	1.10	3.51	2.71	0.80	.....	.....	.....
10	5.40	3.35	2.05	5.54	3.66	1.88	5.42	3.59	1.83	5.80	3.37	2.43	5.78	3.74	2.04	5.49	3.43	2.06	4.53	2.80	1.73	5.03	2.90	2.13	4.54	3.13	1.41	3.60	2.87	.73	.....	.....	.....
15	6.25	2.10	4.15	5.60	1.64	3.96	6.58	1.62	4.96	6.01	1.59	4.42	6.04	1.79	4.25	5.76	2.12	3.64	6.49	2.32	4.17	6.18	2.37	3.81	4.60	2.91	1.69	4.20	3.09	1.11	.....	.....	.....
20	3.98	1.05	2.93	4.84	1.28	3.56	4.86	1.22	3.64	4.08	1.02	3.06	4.84	1.24	3.60	4.78	1.49	3.29	6.02	1.78	4.24	6.24	1.86	4.38	5.07	2.59	2.48	4.64	2.87	1.77	.....	.....	.....
25	2.74	.72	2.02	2.96	.70	2.26	3.00	.73	2.27	2.21	.75	1.46	3.84	.88	2.96	4.02	.90	3.12	4.33	.96	3.37	4.54	1.11	3.43	6.23	2.28	3.95	5.52	2.73	2.79	.....	.....	.....
30	2.61	.73	1.88	2.42	.71	1.71	2.50	.69	1.81	2.10	.69	1.41	3.54	.84	2.70	3.21	.78	2.43	3.26	.83	2.43	3.53	1.08	2.45	5.67	1.49	4.18	6.32	2.14	4.18	.....	.....	.....
35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.14	.89	2.25	4.84	1.20	3.64	5.68	1.56	4.12	.....	.....	.....
40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.01	.98	3.03	4.28	1.36	2.92	.....	.....	.....
50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.94	1.20	2.74	.....	.....	.....
60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.42	1.22	2.20	.....	.....	.....

The changes that took place during the development and maturing of the kernels were nearly the same for all plantings in spite of rather wide variations in climatic conditions. However, the rate at which the changes occurred was tremendously affected by the prevailing temperature. The history of the total sugars began with a medium percentage of sugar, which increased for a time and then decreased as complete maturity approached. The reducing sugars were high in the early stages of development and steadily decreased as maturity advanced. The sucrose was low at first, increased rapidly for a time, and then decreased steadily as the corn matured. These changes are shown in detail in Figures 7 to 10.

The quantity of sugars present was rather uniform for the first seven plantings, always being highest in the corn at the 15-day stage.

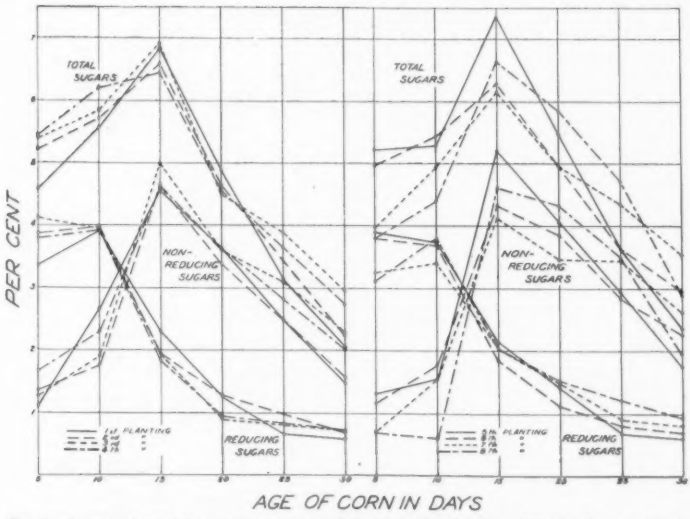

FIG. 7.—Sugar content of the cut corn from ears of the first eight plantings of Golden Bantam sweet corn sampled at different stages of maturity

In the later plantings the highest point was reached at an age greater than in the first plantings, with the temperature as the principal factor affecting the variation. There was no very great change in the ratio of the sugars to each other.

A small but significant difference was apparent in the ratio of total sugars to the total polysaccharides between the early plantings and those made very late, there being a greater proportion of sugar as compared with polysaccharides in the late plantings that matured in the very cool part of the season. Where methods of handling are the same, this greater proportion of sugar in the corn maturing in the cool season should result in a superior canned product. Such an effect was observed in the corn canned from the late plantings in the present experiments, though the improvement in quality was not great. It should be remembered that the greatest effect of cool weather on corn is to slow down the rate at which maturity proceeds.

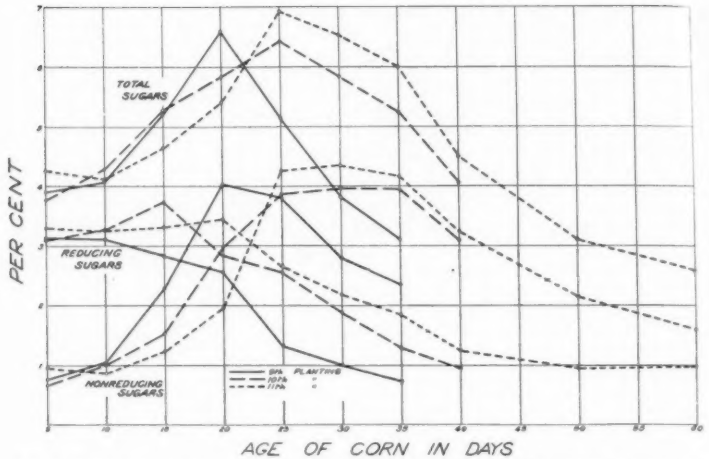

FIG. 8.—Sugar content of the cut corn from ears of the ninth, tenth, and eleventh plantings of Golden Bantam sweet corn sampled at different stages of maturity

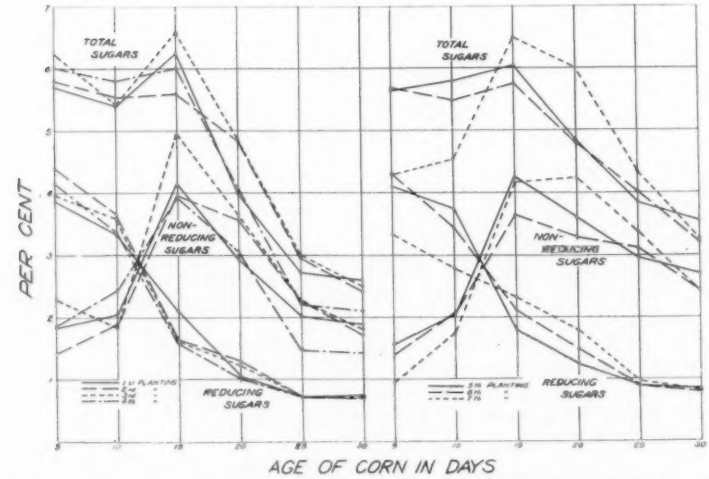

FIG. 9.—Sugar content of the cut corn from ears of the first seven plantings of Stowell's Evergreen sweet corn sampled at different stages of maturity

The rate of change in sugar content is very different from the rate of change in the tenderness of the corn, the two processes being, apparently, very largely independent of each other. The toughness increases very rapidly as the corn gets older, but the sugar content changes less rapidly.

The figures show that Golden Bantam has a slightly higher sugar content at comparable stages of maturity than Stowell's Evergreen.

POLYSACCHARIDES

The polysaccharides in sweet corn seem to be a complex mixture of substances which are chemically or physically different. Approximately one-half of the total amount present in the corn at canning maturity is made up of a water-insoluble portion, which qualitative

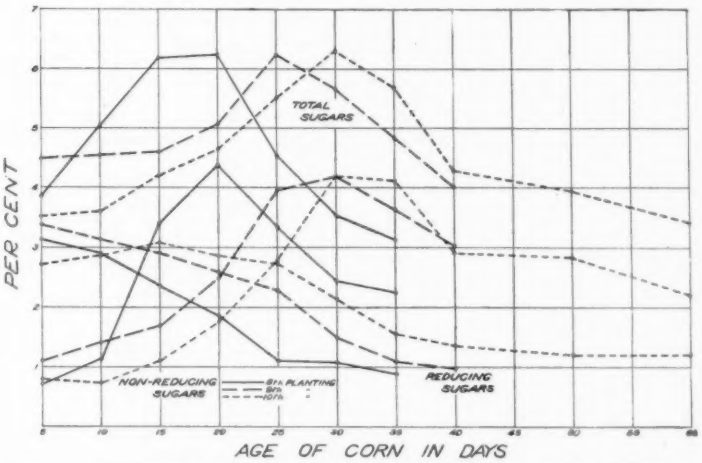

FIG. 10.—Sugar content of the cut corn from ears of the eighth, ninth, and tenth plantings of Stowell's Evergreen sweet corn sampled at different stages of maturity

chemical tests and microscopic examination indicate is composed principally of starch. The other, or water-soluble fraction, usually shows the presence of two substances, one giving a red color reaction with iodine solution, and the other a blue. The nature and proportion of these various substances making up the total polysaccharides have been given particular attention by Lampe and Meyers (7).

From the standpoint of both the canner of sweet corn and the consumer of the canned product the polysaccharides are of great importance, for they are the primary constituents of the corn which affect the consistency of the canned material and comprise the major portion of the nutritive substances. Starch gives to corn a viscous, heavy consistency, while the water-soluble polysaccharides make the canned product more creamy and palatable.

In Table 4 are given the figures for total polysaccharides, calculated as starch, obtained by analysis of the corn from the different plantings harvested at different stages of maturity.

TABLE 4.—*Percentage of total polysaccharides, calculated as starch, in Golden Bantam and Stowell's Evergreen sweet corn at different stages of maturity, from plantings made at intervals throughout the season*

GOLDEN BANTAM

Age of ears in days	Planting										
	1 Apr. 28	2 May 5	3 May 10	4 May 23	5 May 31	6 June 7	7 June 17	8 June 27	9 July 9	10 July 18	11 July 28
5	1.68	1.84	2.02	2.12	2.22	2.42	1.70	1.90	1.87	1.68	1.65
10	1.88	1.97	2.11	2.13	1.86	2.40	1.82	1.68	1.66	1.62	1.76
15	7.97	8.41	8.36	9.73	8.12	7.98	7.37	7.30	2.10	1.26	1.79
20	17.79	19.80	19.96	19.59	16.98	16.61	17.16	14.54	4.32	2.48	2.26
25	26.19	.....	24.81	24.62	23.80	22.17	20.51	17.59	8.07	5.33	4.59
30	30.58	29.31	30.48	28.33	27.47	29.60	22.26	20.36	16.74	8.48	8.14
35	.....	.....	.....	.....	.....	.....	.....	.....	19.86	11.76	11.42
40	.....	.....	.....	.....	.....	.....	.....	.....	.....	17.42	15.92
50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	20.37
60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	24.77

STOWELL'S EVERGREEN

5	1.68	2.08	1.60	2.32	2.02	1.78	1.79	1.50	1.43	1.45	.....
10	1.60	1.68	1.75	1.96	1.97	2.30	1.71	1.65	1.53	1.49	.....
15	5.54	6.77	6.86	6.93	6.31	4.16	4.22	3.98	1.42	1.43	.....
20	12.26	10.98	10.94	11.86	11.07	11.94	10.11	7.24	3.12	1.61	.....
25	16.96	17.43	17.25	17.73	16.63	15.48	15.40	10.35	4.83	2.25	.....
30	21.97	23.70	24.90	24.40	20.40	18.14	18.72	14.90	9.73	4.93	.....
35	.....	.....	.....	.....	.....	.....	.....	19.32	13.72	8.69	.....
40	.....	.....	.....	.....	.....	.....	.....	.....	16.20	13.24	.....
50	.....	.....	.....	.....	.....	.....	.....	.....	.....	16.52	.....
60	.....	.....	.....	.....	.....	.....	.....	.....	.....	19.94	.....

It is seen that during the development and maturing of the sweet corn kernel the polysaccharide content increased steadily. The quantity present in corn of the same age in the first seven plantings did not vary greatly, but the rate at which it accumulated in the corn of later plantings fell off rapidly as the season advanced. A change in the moisture-polysaccharide ratio was therefore observed.

As noted in the case of the total solids, there was found a somewhat greater proportion of sugar to total polysaccharides in the corn of the late plantings than in that of the earlier plantings.

The story of the polysaccharide changes as observed in the present experiments is illustrated in the curves of Figure 11.

DEXTRIN

The water-soluble polysaccharide giving a red color reaction with iodine solution appears to be a dextrin, or a closely related substance, and since it comprises the major portion of the water-soluble fraction, the figures for total water-soluble polysaccharides given in Table 5 are calculated as dextrin, although there was more or less material present giving a blue coloration with iodine.

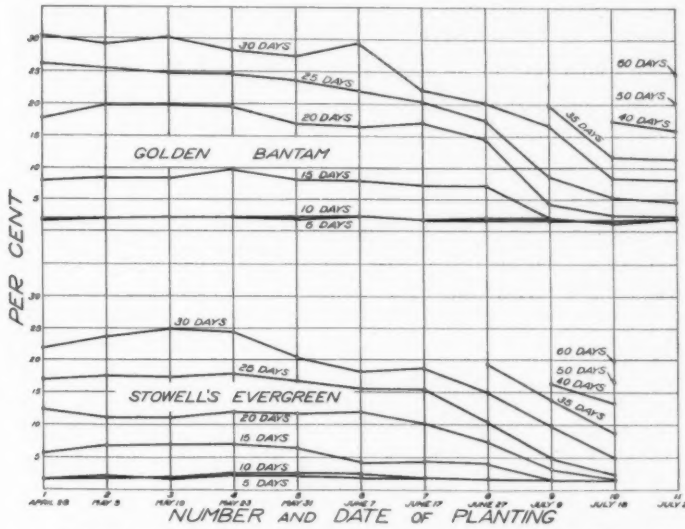

FIG. 11.—Total polysaccharide content of the cut corn from ears harvested from the different plots of Golden Bantam and Stowell's Evergreen sweet corn at different stages of maturity

TABLE 5.—*Percentage of water-soluble polysaccharides, calculated as dextrin, in Golden Bantam and Stowell's Evergreen sweet corn at different stages of maturity, from plantings made at intervals throughout the season*

GOLDEN BANTAM

Age of ears in days	Planting										
	1 Apr. 28	2 May 5	3 May 10	4 May 23	5 May 31	6 June 7	7 June 17	8 June 27	9 July 9	10 July 18	11 July 28
5	0.06	0.04	0.03	0.06	0.08	0.13	0.08	0.07	0.05	0.08	0.05
10	.15	.09	.20	.08	.13	.40	.05	.06	.04	.08	.10
15	3.32	3.46	3.48	3.05	3.80	3.32	3.06	3.04	1.21	.16	.08
20	8.68	9.66	9.55	9.54	8.28	8.08	8.36	7.09	1.80	.98	.75
25	12.93		12.28	11.51	12.34	10.96	10.13	8.28	4.48	2.92	1.89
30	15.83	14.48	14.33	14.66	14.08	13.92	11.73	10.06	8.16	4.51	3.01
35									9.98	6.45	5.57
40										8.68	7.49
50											10.07
60											11.60

STOWELL'S EVERGREEN

5	0.04	0.05	0.04	0.05	0.03	0.04	0.04	0.02	0.03	0.03	
10	.04	.04	.05	.05	.05	.10	.07	.10	.11	.03	
15	2.31	2.82	2.85	2.88	2.63	1.73	1.75	1.65	.10	.04	
20	5.98	5.36	5.34	5.76	5.40	4.27	4.93	3.09	1.15	.10	
25	8.37	8.61	8.64	8.72	8.01	7.28	7.61	5.05	2.05	.43	
30	11.24	12.11	12.01	12.62	10.11	8.54	9.68	7.36	3.95	1.05	
35								9.09	6.45	3.92	
40									8.07	6.46	
50										8.16	
60										10.32	

By comparing the figures of this table with those for total polysaccharides in Table 4 it is seen that in the early stages of development the proportion of the water-soluble fraction was much less than in the older corn. No significant effect of seasonal factors on the ratio of water-soluble to total polysaccharides, however, was found. Curves showing the history of the water-soluble polysaccharides in these experiments are given in Figure 12.

CANNING TESTS

From the practical standpoint, the quality of the corn in the can is the most important consideration in studies of this sort. As before stated, canning tests were made upon the corn of each plot at the ages of 15, 20, 25, and 30 days. After husking, trimming, and washing, the corn was cut from the ears by hand machine, the knives

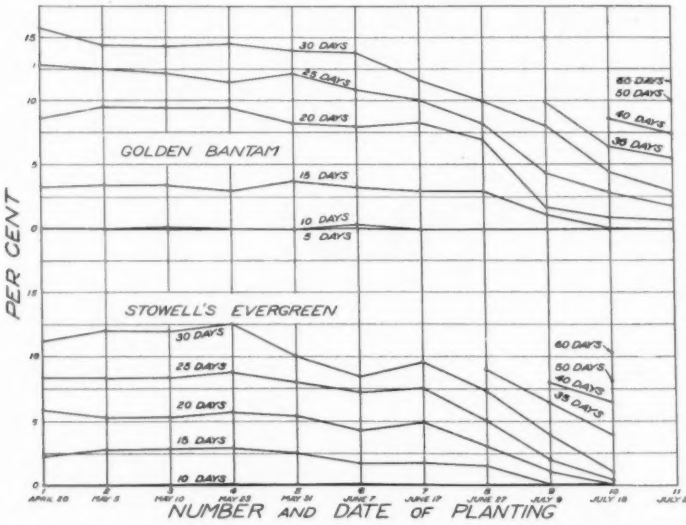

FIG. 12.—Water-soluble polysaccharide content of the cut corn from ears harvested from the different plots of Golden Bantam and Stowell's Evergreen sweet corn at different stages of maturity

being arranged so as to remove the outer one-half to two-thirds of the kernel, and the remainder of the kernel contents was scraped from the cob by the mechanical scrapers of the machine. The cut corn was then weighed and enough brine (containing 2 per cent salt and 6¼ per cent sugar) added to it to give the ratio of cut corn to brine, by weight, of 4 to 1.

The corn was then precooked in a steam-jacked cooker provided with a mechanical stirring device, and the cooking continued, with constant stirring, until the temperature reached 85° to 90° C. It was filled into the cans immediately, the cans were sealed, and the processing performed promptly. The procedure was the same for each lot of corn.

By following a uniform procedure in the canning tests it was possible to observe any variations in quality in the canned product due strictly to seasonal factors.

In judging the quality of the cut-out corn, attention was given particularly to tenderness, consistency, flavor, and sweetness. The results obtained follow.

GOLDEN BANTAM

In the first seven plantings the corn showed no significant differences at the various stages. Prime canning condition was found to center around the 20-day stage, the 15-day corn being too immature and the 25-day corn too far advanced for best quality. The 25-day corn of the seventh planting, however, was not quite so mature as that from those immediately preceding. The corn from the eighth plot was almost prime at the 25-day stage, though a very good product was obtained from the 20-day corn. There was observed here a slightly lengthened period during which first-quality canned corn could be produced. In the product from the ninth planting the corn was found to be too immature at 25 days of age and about prime at the 30-day stage. The corn from the tenth planting was slightly too immature at the 30-day stage, being in about the same condition at this age as the corn of the first plot at the 15-day stage of maturity.

STOWELL'S EVERGREEN

In the case of this variety the corn of the first four plantings showed no significant differences in the quality of the products from corn of like age. The 15-day corn was tender and sweet, but the product was watery and the corn too immature to make possible the packing of a product of first quality. At the 20-day stage the corn was slightly under prime, from the standpoint of consistency, but was sweet and tender. At 25 days the kernels had toughened perceptibly and the natural sweetness had largely disappeared, but the consistency was good. The corn 30 days old was tough and starchy, being well past the canning stage.

Prime canning maturity in the corn from the first four plantings, therefore, was found to be close to but slightly beyond the 20-day stage.

In the corn from the fifth planting a slight slowing down in the rate of development was noted. At the 20-day stage the product was tender and sweet but somewhat lacking in body, while the 25-day corn was nearly prime. At the 30-day stage the corn yielded a product of fair consistency, but the kernels were tough. In the case of the sixth planting the findings were similar to those just described for the fifth, the corn being in prime canning condition at about the 25-day stage.

The cut-out material from the seventh planting showed a slight further slowing down in the rate of maturing, in this case the 25-day corn being at the lower limit of maturity for prime consistency. At 30 days of age the corn was sweeter than that at the 25-day stage of the first four plantings, and though a little tough, was satisfactory from the standpoint of consistency. In the material from the eighth plot the corn at the 30-day stage was sweet and of about the same consistency as that of the first four plantings at 20 days. The corn of the ninth planting was even less mature at comparable stages, that 30 days old yielding a product that was too watery and immature for first quality.

The corn of the tenth planting was utilized in the study of frost injury, the findings of which will be discussed presently.

It will be seen from these observations, therefore, that the period during which the ear of corn develops has a very great deal to do with the rate at which maturity progresses and, accordingly, with the quality of the canned product. The correlation of these findings with the data of related studies and with the seasonal factors themselves will be undertaken in the general discussion which follows the presentation of experimental results.

FROST INJURY

It is commonly considered by sweet-corn canners that if corn becomes "frost bitten" it is seriously injured for canning purposes, and a light frost is thought to cause considerable deterioration in the quality of the corn. So far as the writers have been able to learn, almost no work has been published on the effect of frost injury upon the quality of canned corn. Bushey (*2*) and Spitzer and his associates (*10*) have made studies upon the composition of soft corn (field corn), but their results are hardly comparable with those given here, as most of their analyses compare thoroughly ripened corn with corn more or less immature. A higher moisture content and larger quantities of amide nitrogen were generally found. Kiesselbach and Ratcliff (*6*) have shown that freezing the immature corn injures it for seed purposes, and it is also injured if there is a high moisture content.

The plantings in the present experiments furnished material admirably suited to a study of the effect of frost. By going through the last plantings of each variety one could obtain samples at almost any stage of maturity.

On the night of October 21 a light frost occurred which resulted in the killing of approximately two-thirds of the leaf area of most of the leaves. The bases of the blades and the stalks and ears were not injured materially. Canning tests were made on the afternoon of the twenty-first on corn from ears of Stowell's Evergreen 30 days and also 35 days old, and likewise from ears of Golden Bantam 30 days old. The tests were repeated two days later. Chemical samples were also taken. In an examination of the cut-out material no difference whatever could be found in the corn canned before as compared with that canned after the frost, unless perhaps a slight difference in consistency, which was to be expected of corn two days older. The results of the chemical analyses shown in Table 6 indicate very little alteration in the chemical composition, and nothing that could be attributed to frost injury. The normal ripening processes continued, but at a much slower rate because of the lower prevailing temperature.

TABLE 6.—*Percentage composition of Stowell's Evergreen and Golden Bantam sweet corn before and after frost*

Variety	Date of sampling	Total solids	Total polysaccharides as starch	Water soluble polysaccharides as dextrin	Sugars, as invert		
					Total	Reducing	Non-reducing
Stowell's Evergreen, 30 days old	Oct. 21	16.84	6.66	2.94	6.11	1.75	4.36
	Oct. 23	17.03	7.29	3.11	5.98	1.57	4.41
Stowell's Evergreen, 35 days old	Oct. 21	22.14	12.07	5.68	5.02	1.57	3.45
	Oct. 23	23.27	13.29	6.25	4.92	1.29	3.63
Golden Bantam, 30 days old	Oct. 21	16.16	5.83	2.10	6.98	2.30	4.68
	Oct. 23	16.42	5.88	2.15	6.82	2.43	4.39

During the period following the frost of October 21 up to the 16th of November the corn continued to mature, though at a very slow rate, which affected the canned samples correspondingly.

On the night of November 16 a heavy freeze occurred in which the stalks and ears were completely frozen. Canning samples were taken early in the morning after the freeze and again five days later. Corn of two stages of maturity was used, one lot from ears 50 days old and the other from ears 60 days old, these being not far removed either way from prime canning maturity.

The quality of the corn in the cut-out samples showed much less difference in the quality of the product than was expected. The corn canned on the morning after the freeze was normal in appearance and flavor. That canned five days later showed a little browning, which was apparently caused by the oxidation of tannins in the cob particles removed with the corn in cutting, and the appearance of the product was, therefore, not quite so attractive. There was a slight "cobby" flavor to the corn, but this was not very marked, and had one not known the history of the corn it probably would have been consumed without much hesitation.

Chemical samples were taken on the morning after the freeze and at intervals thereafter. Table 7 shows the results of the analyses.

TABLE 7.—*Percentage composition of Stowell's Evergreen and Golden Bantam sweet corn sampled immediately and at intervals after complete freezing*

Variety	Date of sampling	Total solids	Total polysaccharides, as starch	Water soluble polysaccharides, as dextrin	Sugars, as invert		
					Total	Reducing	Nonreducing
Stowell's Evergreen, 50 days old	Nov. 17	22.62	12.68	5.98	4.90	1.26	3.64
	Nov. 22	23.53	13.67	7.07	4.56	1.51	3.05
	Nov. 27	24.35	13.69	7.08	5.12	2.26	2.86
	Dec. 2	22.32	12.81	6.68	4.97	2.54	2.43
	Dec. 7	22.96	12.52	6.51	4.43	2.90	1.53
Stowell's Evergreen, 60 days old	Nov. 17	30.03	19.94	10.32	3.42	1.22	2.20
	Nov. 22	29.06	18.29	9.24	3.33	1.58	1.75
	Dec. 2	28.62	17.76	9.19	3.64	2.01	1.63
	Dec. 7	29.55	19.58	9.62	3.98	2.32	1.66
Golden Bantam, 50 days old	Nov. 17	30.33	18.64	9.21	3.90	2.27	1.63
	Nov. 27	31.54	19.60	9.66	3.69	3.09	.60
	Dec. 2	31.28	19.08	9.02	3.04	2.50	.54
Golden Bantam, 60 days old	Nov. 17	34.95	23.92	11.26	3.58	.98	2.60
	Nov. 27	35.29	24.77	11.60	2.88	1.64	1.24
	Dec. 2	35.75	23.52	11.16	3.73	2.28	1.45

The results were somewhat irregular because of errors in sampling. The moisture content did not change very materially during the entire time, though there were indications of a slight decrease. The total polysaccharides behaved in about the same way, increasing when the moisture decreased, and vice versa. There appeared to be a very marked tendency for the reducing sugars to increase and the sucrose to decrease. It is not certain, however, that all the increase in reducing sugars arose from the inversion of sucrose.

The climatic conditions subsequent to the freeze were not such as to cause much drying or rapid fermentation of the corn. After five days the cob and chaffy material at the base of the grains began to turn brown, and soon afterwards the grain itself became somewhat discolored. This rendered it unfit for canning.

The rate at which deterioration will occur after the corn is frozen depends upon climatic conditions. If it is very warm, completely frozen material will discolor more rapidly and fermentation may take place. Practically no fermentation occurred in the corn in these tests. Between 10 and 15 days after the freeze an occasional ear was found which was invaded by molds. After 15 days the number increased rapidly, and in time practically all the remaining ears were spoiled in this way.

GENERAL DISCUSSION

To assist in the correlation of seasonal conditions with the variations observed in the field plots and in the corn derived therefrom Table 8 has been prepared. This table indicates in dates and days the progress of growth and maturity of the corn from the different plots. The times specified under "Date of silking" were the mid-silking dates, or those days on which the peak of silking occurred, as determined by the daily tagging records, and in the column showing the time at which the corn came to canning maturity corresponding dates are given. The exact dates, in this latter case, were derived by adding to the date of silking the number of days required thereafter for the corn to arrive at canning maturity, as shown in the last column of the table. The data of this last column were secured by a study of two factors, namely, the quality of the cut-out corn from the practical canning tests and the moisture content of the raw corn as determined by chemical analysis, which were in close agreement.

TABLE 8.—*Effect of seasonal conditions on the development and maturing of Golden Bantam and Stowell's Evergreen sweet corn at Arlington Experiment Farm during the season of 1924*

GOLDEN BANTAM

Number of planting	Date of planting	Date of silking	Days from planting to silking	Date of canning maturity	Days from planting to canning maturity	Days from silking to canning maturity
1	Apr. 28	July 16	79	Aug. 5	99	20
2	May 5	July 21	77	Aug. 10	97	20
3	May 10	...do...	72	...do...	92	20
4	May 23	July 23	61	Aug. 12	81	20
5	May 31	July 30	60	Aug. 19	80	20
6	June 7	Aug. 3	57	Aug. 23	77	20
7	June 17	Aug. 11	55	Aug. 31	75	20
8	June 27	Aug. 21	55	Sept. 13	78	23
9	July 9	Sept. 2	55	Oct. 2	85	30
10	July 18	Sept. 14	58	Oct. 24[a]	98	40
11	July 28	Sept. 24	58			
12	Aug. 9	Oct. 13	65			

STOWELL'S EVERGREEN

1	Apr. 28	July 29	92	Aug. 21	115	23
2	May 5	July 31	87	Aug. 23	110	23
3	May 10	Aug. 3	85	Aug. 26	108	23
4	May 23	Aug. 4	73	Aug. 27	96	23
5	May 31	Aug. 11	72	Sept. 3	95	23
6	June 7	Aug. 14	68	Sept. 8	93	25
7	June 17	Aug. 19	63	Sept. 13	88	25
8	June 27	Aug. 29	63	Sept. 29	94	31
9	July 9	Sept. 15	68	Oct. 24[a]	107	39
10	July 18	Sept. 25	69			
11	July 28	Oct. 16	80			

[a] This was the date on which the peak in canning maturity would have been reached had not the frost on the night of Oct. 21 occurred. The data on which this statement is based were obtained from ears tagged before the peak of silking was reached, which were sampled before Oct. 21.

Considering first the data concerned with Golden Bantam, it will be noted that the length of time required for the plantings to come to the peak of silking ranged from 79 to 55 days, an extreme variation of 24 days. The most rapid development was recorded in plots 7, 8, and 9, which were planted on June 17 and 27 and July 9, respectively. In the tenth planting there was a distinct lengthening of the growing period.

In the figures for the days required for the corn to reach canning maturity it is seen that the time ranged from 99 days in the first planting to 75 days in the seventh, beyond which the time increased rapidly to 98 days in the tenth.

With respect to the length of the period between silking and canning maturity no difference was found in any of the plots planted up to June 17, the period in all being 20 days. In the eighth planting a little lengthening of the period was noted, and in the ninth the time was increased to 30 days. Forty days were required for the corn of the tenth plot to arrive at canning maturity after silking.

In the data for Stowell's Evergreen similar conditions are observed. Here the length of the period from planting to the peak of silking ranged from 92 days in the first plot to 63 days in the seventh, an extreme variation of 29 days. The length of this period for the seventh and eighth plots remained stationary at 63 days, but beginning with the ninth a distinct lengthening was observed, which increased more and more up to the eleventh planting, when the length of the period was 80 days.

Similar results were obtained with respect to the length of time from planting to midcanning maturity in the different plots. In the first planting this period amounted to 115 days, decreasing in succeeding plantings to 88 days in the seventh and lengthening again in the eighth and ninth.

The figures giving the length of the period from silking to canning maturity in Stowell's Evergreen show results similar to those observed in Golden Bantam. Here, however, the period was 23 days for the first five plantings, the succeeding planting showing a progressive lengthening up to 39 days in the ninth.

It is seen, therefore, that both varieties, though very different in most of their characteristics, responded in an identical manner to certain external influences. A careful analysis of the data presented here shows that in all those variations where there was a distinct change toward a longer growth and maturing period the time at which the change occurred in both varieties was in the early days of September. Thus in the case of Golden Bantam the period of time between planting and silking began to increase at between September 2 and September 14, the length of the period from planting to canning maturity began to increase between August 31 and September 13, and the period from silking to canning maturity showed an increase at the same time.

In the Stowell's Evergreen the period from planting to silking began to lengthen at between August 29 and September 15 and the period from silking to canning maturity at between September 3 and September 8. The period from planting to canning maturity began to lengthen at between September 13 and 29, later than at first would appear consistent with the foregoing figures, but not

inconsistent when it is realized that the growing period prior to silking in this case occurred during the most favorable growing season, thus offsetting in the total period the lengthening of the time between silking and canning maturity, as indicated in the figures of the final column.

It would appear that the prime factor affecting the rate of maturing in these plots of corn was that of temperature, for with the gradually rising seasonal temperature there was a progressive shortening of the growing and maturing periods and a distinct lengthening of these periods at the time of abrupt change from summer to late autumn temperatures taking place early in September. The constant length of the period from silking to canning maturity in the first seven plantings of Golden Bantam and the first five plantings of Stowell's Evergreen corresponds to the interval of time from July 16 to September 3, which, as reference to the curves of Figure 1 will show, had an unusually uniform summer temperature.

In the previous paper, to which reference has already been made, attention was called to the fact that variations in the time of maturing of different varieties was due to the length of the growing period of the plant—that is, from the time of planting to the time of silking rather than to the length of the period from silking to canning maturity, which was fairly uniform for all varieties. Hopper (*5*) has made the same observation. While in the present study this held true for the plantings made at the usual season, it did not hold for the later plantings, and future interpretation of experimental results along this line will need to take seasonal factors into consideration.

Change in temperature is quickly reflected both in the development of the plant and in the rate at which the sugar, starch, and other constituents are stored in the kernels. Sudden lowering of the temperature while the plant is still small results in an immediate slowing down in the rate of growth; coming during the flowering season, the tasseling and silking are promptly delayed, the normal processes being resumed upon the return of favorable temperature; coming during the maturing period of the ear, the enzymatic activities are retarded and the development of the kernels is checked; all of which go to show that temperature conditions are intimately related to the vital functions of the sweet-corn plant.

Referring again to the results of the chemical analyses, we find further evidence in support of this view. The relation of temperature to the moisture content of the corn has already been emphasized. In the data showing the transformations in the amount and proportions of the different sugars in the corn of the different plots it is found that the first significant variations from the figures for the corn of the early plantings occur in those samples taken after the pronounced temperature change beginning in early September had affected the rate of maturing of the corn. Like effects are observed in the figures on polysaccharides, and confirmatory evidence is also found in the data on the rate of increase and degree of toughness in the corn of the various plots.

One fact of practical significance which has been brought out in these studies on the relation of temperature to quality is that because of the slowing down in the rate at which maturity in sweet corn proceeds during the cooler season there is a longer period during which a

rst-quality product can be canned, the corn remaining in canning condition considerably longer than in the case of that maturing during the hot season. This has been emphasized in the discussion concerning increase in toughness, but the results of chemical analyses point to the same fact.

The rôle played by rainfall in the vital processes of sweet corn has been the subject of particular study in the present investigations, and its very important relation to the vegetative activities of the plant has already been discussed. One might expect to find also in the chemical transformations taking place within the developing corn kernels a very close relation between soil moisture and the chemical composition of the kernel constituents, which would be reflected first of all in the moisture content of the corn kernels, with corresponding variations in the other chemical constituents. Care was taken to check over all analyses to discover any correlation between the moisture content of the corn samples and the drought and rainfall conditions of the season.

The drought conditions that prevailed during the last of July and the first 12 days of August, however, did not affect appreciably the moisture content of the samples taken during this period. The month of October was also practically rainless, but the temperatures were considerably lower than during the drought of July and August, and the evaporation of soil moisture was correspondingly less. There was no decrease in the moisture content of the samples taken during the drought of October; on the contrary, the moisture content of these samples was even higher than in the corn of corresponding age from the earlier plantings, due, evidently, to the decrease in the rate of maturing because of the lower temperatures.

From the experimental evidence presented, it is clear that soil moisture conditions directly affect the vegetative activities of the plant and are reflected particularly in the yield of corn, but while soil moisture does determine to a very large degree the amount of material which the plant is able to manufacture, it does not, apparently, have any appreciable effect on the chemical composition of the kernels up to at least 25 days of age.

Sunshine does not seem to be a limiting factor in the maturing of sweet corn. Its variations are accompanied by other varying factors which complicate the results, so that its effect is uncertain. No general or specific effect has been noted in these studies that could be attributed to it.

Taking into consideration the variations in chemical composition of corn as influenced by age and by environmental conditions, particularly temperature, it is apparent that analytical data on plant products which take no account of these factors are of very limited value.

In the earlier publication, to which reference has already been made, the writers showed that quality in sweet corn is determined primarily by the degree of maturity of the corn when canned. Any influence, therefore, affecting the rate at which maturity proceeds would have a direct relation to the quality of the canned product. It has been shown in the present study that the time required for the corn of the first seven plantings of Golden Bantam to reach canning maturity was the same, and no distinguishable differences in quality

could be detected in the product from corn of the same age. The same was true for the first five plantings of Stowell's Evergreen. In the later plantings where the rate of development was slowed down the corn of the same ages was correspondingly immature, so that to secure the highest quality in the canned product older corn had to be used. In addition to this, however, there was observed in the corn of the late plantings a higher degree of sweetness and tenderness in the corn of prime consistency than was observed in that from the earlier plantings having like consistency, indicating that the corn maturing during the cool autumn temperatures is somewhat superior in quality to that maturing during the warmer season.

The relative merits of the canned product from Golden Bantam and Stowell's Evergreen corn has been the subject of considerable discussion among both canners and users of canned corn. The findings of the present study as bearing on this matter are, therefore, of some interest. It was found that at comparable stages of maturity Golden Bantam was tenderer than Stowell's Evergreen, as determined by kernel puncture tests, and chemical analyses made of the corn at the different stages of maturity showed that the sugar content was, on an average, slightly higher in the Golden Bantam. It is not known that these facts would hold for all strains of these varieties, but they were sufficiently pronounced in the present case to be significant.

Frost as a hazard in sweet-corn canning seems, from the results of the present study, to have been somewhat overestimated. Its seriousness as affecting the quality of the corn in the can is dependent, apparently, on the severity of the frost and the temperature conditions following. In the present case a light frost had no perceptible effect and a heavy freeze made its effect felt only after several days. Mere freezing of the corn does not of itself, so far as could be determined from the samples canned in these experiments, have a deleterious effect on the quality of the cut-out corn.

The sweet-corn grower who desires to use the stover as green feed or for silage is usually anxious that the corn be harvested before it is frosted. There is, of course, a certain amount of loss in succulence of the corn, and it probably is somewhat less palatable to stock, but there is, apparently, no loss in food value as a result of freezing, and except for the loss of some of the material during the harvesting operations caused by its brittle condition after freezing, no particularly harmful effects follow frost injury.

SUMMARY

Seasonal factors, through their influence on the rate of development and maturing of sweet corn, are important in determining the quality of the canned product. In the present experiments the rate of growth, the length of the growing period, the size of the plant and of the ear, the yield of corn, and the rate at which maturity proceeded were modified very materially by variations in the environmental conditions.

The number of days from planting to the time of silking ranged from 55 to 79 for Golden Bantam and from 63 to 92 for Stowell's Evergreen. The principal factor responsible for these variations was temperature. The longest time required to reach the silking stage

was in plantings made early in the spring; the shortest time in plantings made in early summer. As the coolness of autumn approached, the time between planting and silking was correspondingly increased.

The number of days from the time of silking to the time most favorable for canning ranged from 20 to 40. Here also the tests indicated that temperature was the principal factor determining the length of the period. As the maturing period passed into the cool part of the autumn, the most favorable age for canning was correspondingly increased.

The toughness of the corn as measured by its resistance to puncture increased continuously throughout the period of its development. Toughness has a very important influence on the quality of the canned material, for as toughness increases the quality of the corn is progressively lowered until it becomes unsuited for table use. Stowell's Evergreen at corresponding ages was somewhat tougher than Golden Bantam.

The yield of cut corn increased rapidly in the corn maturing in midsummer. In the cool autumn it increased more slowly but for a longer time. The proportion of cut corn to cob and husk continued to increase throughout the entire period of development and maturing of the ears.

The percentage of moisture in the developing grains decreased continuously during the growth and maturing of the ears. It decreased most rapidly during the hot summer days and less rapidly in the late fall. Stowell's Evergreen was found to be characteristically higher in moisture content than Golden Bantam. Corn in prime canning condition had a moisture content ranging from 25 to 30 per cent.

The total sugar content of the very young grains was medium to low, increased for a time as development proceeded, and then decreased as maturity approached. The rate at which the changes occurred depended primarily on the prevailing temperature. Whenever a change in temperature occurred it affected the development of the ear during that period regardless of the stage of maturity.

The sucrose was low in the early stages of development, increased rapidly for a time, and then decreased slowly until maturity was complete. The changes were also affected by the prevailing temperature, so that in the cool autumn the age at which the highest sugar content occurred was greater than in the early plantings.

The reducing sugars were high in the early stages of development of the corn and decreased steadily as maturity advanced, the rate depending on the temperature.

The polysaccharides were found to consist of a portion soluble in cold water, probably chiefly dextrin, and a portion insoluble in cold water, which was principally starch. When the corn was in prime canning condition about one-half of the total polysaccharides were water soluble, and environmental conditions did not seem to alter this ratio to any extent. Owing to the slower rate at which maturity progressed, the quantity of polysaccharides was smaller in the corn developing during the late autumn than in corn of the same age developing during the hot season.

Of the seasonal factors concerned with the growing and canning of sweet corn, temperature was found to be the most important as

affecting the quality of the canned product. The rainfall had a very marked effect upon the vegetative activities of the plant, but produced no significant effect on the chemical composition of the cut corn or the quality of the canned product. No specific effect of sunshine could be detected in the experimental findings of this study.

Light frost had no significant effect on the composition of the corn or the quality of the canned product. For the first few days after a heavy freeze the canning quality was almost equal to that of the unfrozen corn, but the quality deteriorated rapidly thereafter owing to the discoloration and the activities of microorganisms.

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EFFECT OF FEEDING AND MANAGEMENT OF SHEEP ON THE TENSILE STRENGTH AND ELASTICITY OF WOOL[1]

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PREVIOUS INVESTIGATIONS

The earlier work on the tensile strength and elasticity of wool at this station has already been reported in a paper in which some of the literature on the subject was reviewed (*8*).[2] An improved testing device was described, the observations which should be taken in running tests on wool fibers were demonstrated, and the interpretation of the data from such tests was illustrated. It was shown that breaking stress has a much greater variability than tensile strength, and that the elastic limit and Young's modulus may be more important indications of the value of a set of wool fibers in fabrics than the breaking stress.

Since the appearance of the paper mentioned above, additional information has been published by Hardy on methods of testing wool fibers (*4*, *5*) developing the fact that humidity affects the ultimate strength and the elastic limit of wool fibers.

Types of apparatus for testing wool were described by Henley (*6*) and Macha (*7*).

There have been a number of reports showing the effect of feeding and management of sheep on the growth of wool. One of the earlier studies was made by Cooke and Jones (*2*) in which the feeding to Merino ewes of "carbonaceous" as contrasted with "nitrogenous" rations produced no measurable differences in diameter of fiber as indicated by their results. They point out, however, that the wool fibers of a few of the sheep that "did not do well" were "shrunken in diameter."

Craig (*3*, *p. 18–19*) used Shropshire wethers in a study of the relative effects of "carbonaceous" and "nitrogenous" rations. He found that six wethers fed the "nitrogenous" ration clipped 2.4 pounds more unwashed wool and 0.6 pound more washed wool than six wethers fed the "carbonaceous" ration. The additional weight of unwashed wool was credited "in a limited degree, to the amount of yolk in the fleeces of the lots."

Skinner and Smith (*10*) report a difference of 0.4 pound more wool from ewes fed a dry ration than from those fed a succulent ration (containing corn silage). They do not, however, credit this increase to the difference in the rations.

Feeding either calcium sulphate or a ration high in sulphur contrasted with a ration low in sulphur seemed to have no effect on the gross weight of the fleece, on the percentage of clean wool, on the percentage of sulphur in pure wool fiber, or on the percentage of yolk (*9*).

[1] Received for publication June 1, 1926; issued December, 1926.

[2] Reference is made by number (italic) to "Literature cited," p. 1089.

Bray (*1*) reported some studies of density, breaking stress, and elasticity of fibers of Dorset, Shropshire, Merino, and crossbred sheep.

METHOD OF TESTING THE FIBERS

The method of testing the wool fibers in this study was essentially that described by Miller and Tallman (*8*). The readings taken were (1) stretch by each increment of weight or stress of 5 dgm., (2) elastic limit point, (3) total stretch at the breaking point, (4) breaking stress, and (5) diameter. The diameters were averages of 10 readings on each fiber. The fibers were mounted in Canada balsam and the readings were taken with a compound microscope.

Small locks of about 25 fibers were separated from the main sample and every fiber in these locks was tested. In this way the longer or more prominent fibers were not tested to the exclusion of the shorter, finer, and less conspicuous fibers. The flesh or inner end of the fiber was placed in one jaw of the testing machine so that the wool grown during the test period was certain to be subjected to the test.

Since facilities were not available for maintaining constant temperature and humidity and especially since the effect of the humidity of the breath and prespiration of the operator could not be eliminated, no attempt was made to control these factors in the testing room. All samples were kept in a desiccator containing calcium chloride for 24 hours before the beginning of the test. Only the small locks were exposed to humid air during the test. With the exception of the earlier work all testing was completed within three months after shearing.

In order to equalize the effect of any tendency to change the routine of the test by the operator, alternate samples from the two lots were tested. The samples were not scoured before testing. The effect, if any, of hardening of the "grease" or "yolk" would also be equally distributed between the lots.

Naturally some phases of the method are more or less arbitrary. The value of the results for comparative purposes depends on the ability of the operator to maintain a constant speed for the various operations. A definite order of procedure was worked out which was designed to occupy his time at every stage of the operation. The measurements of length of staple were taken after shearing. Each value is the average of 6 to 9 measurements of as many locks of wool.

EXPERIMENTAL MATERIAL AND RESULTS

In 1916 a small group of registered Rambouillet ewes from the flock owned by the station was put into a range band and kept under average range conditions for a year. Samples of wool from these ewes were taken in 1917. In 1916 these ewes had raised a few lambs, and samples of their fleeces were also taken in 1917. These samples were compared with those taken from mature ewes and from yearlings ewes and wethers, respectively, that were kept under very good farm conditions during the year.

In 1918 samples were obtained from mature ewes kept under semirange conditions and from ewes kept under very good farm conditions, both lots coming originally from the flock owned by the station.

TABLE 1.—*Tensile strength and elasticity of wool from aged ewes, 1917*

LOT 1

(AGED EWES, IRRIGATED FENCED PASTURE, GOOD FEED IN WINTER, SHELTER)

Sheep No.	Stretch	Break	Diameter	Average elongation	Tensile strength	Young's modulus	Elastic limit on equal area
	Mm.	*Dgm.*	*μ*				
392-696	7.85±0.248	59.60±0.937	15.40±0.115	0.762±0.0081	141,600±1,895	660,000±10,640	0.5589±0.0086
394-859	3.96± .169	36.50± .809	13.08± .135	[a] .882± .0135	124,800±3,361	[a] 786,600±14,760	.6228± .0158
406-980	11.88± .297	50.61± .958	12.55± .162	[b] .801± .0128	186,400±3,194	[b] 845,800±18,440	.7067± .0146
476-477	6.27± .236	59.70±1.148	14.82± .196	.696± .0074	157,900±2,459	789,000±15,400	.6736± .0121
Averages	7.49±0.121	51.60±0.485	13.96±0.077	0.785±0.0054	152,700±1,395	770,300± 7,530	.6405±0.0065

LOT 2

(AGED EWES; RANGE CONDITIONS)

80-403	7.00±0.202	48.00±0.910	12.70±0.122	0.890±0.0132	170,000±2,248	839,000±14,000	0.7235±0.0106
221	7.04± .310	51.90±1.226	13.52± .155	[c] .782± .0092	159,300±1,979	[c] 831,800±14,020	.6675± .0107
393-961	7.68± .263	47.50± .674	12.76± .082	.856± .0114	165,100±2,904	834,600±10,930	.7104± .0082
401-847	8.80± .229	47.85± .843	12.40± .110	.882± .0145	176,600±2,425	914,600±12,510	.7229± .0102
405	5.40± .209	55.55± .819	13.56± .138	.787± .0088	175,600±2,740	838,800±15,480	.7552± .0137
404-979	6.72± .229	52.15±1.012	13.39± .115	.818± .0094	167,800±2,236	828,400±12,150	.7190± .0097
Averages	7.11±0.099	50.49±0.380	13.05±0.050	0.836±0.0046	169,100± 927	847,900± 5,410	.7164±0.0043

[a] 88 fibers-12 fibers failed to withstand more than 10 dgm.
[b] 80 fibers-20 fibers failed to withstand more than 10 dgm.
[c] 94 fibers-6 fibers failed to withstand more than 10 dgm.

TABLE 2.—*Tensile strength and elasticity of wool from yearling wethers and ewes, 1917*

YEARLING WETHERS

(IRRIGATED FENCED PASTURES; GOOD FEED IN WINTER; SHELTER)

Sheep No.	Stretch	Break	Diameter	Average elongation	Tensile strength	Young's modulus	Elastic limit on equal area
	Mm.	*Dgm.*	*μ*				
519	9.18±0.254	53.30±1.066	14.05±0.118	0.888±0.0133	150,600±2,017	684,000± 7,410	0.6079±0.0077
536	5.19± .236	56.90±1.281	14.17± .148	.798± .0101	161,700±2,904	760,600±12,240	.7188± .0119
548	6.04± .270	53.75±1.207	15.71± .121	.829± .0115	123,800±2,380	570,400±10,140	.5101± .0088
554	6.33± .263	65.85±1.674	15.05± .205	.790± .0108	164,000±2,782	691,400±13,340	.7177± .0119
555	5.16± .216	72.10±1.349	16.54± .175	.762± .0081	151,100±2,262	581,900±10,580	.7328± .0096
559	6.78± .290	60.70±1.281	15.78± .148	.813± .0074	135,800±2,249	581,000± 8,600	.6060± .0085
567	6.68± .308	54.75±1.200	14.75± .136	.806± .0074	146,000±2,925	652,500± 9,020	.6296± .0099
Averages	6.48± .100	59.62± .494	15.15± .058	.812± .003	147,600± 955	646,000± 3,920	.6461± .0037

YEARLING EWES

(SAME PASTURES AND FEED AS ABOVE)

506	6.29±0.243	82.75±1.551	16.34±0.121	0.661±0.0081	171,600±2,616	658,500± 8,350	0.7767±0.0143
530 [1]	8.97± .283	138.30±2.428	22.20± .216	.509± .0060	159,900±2,214	520,700± 8,340	.6621± .0093
508	9.17± .344	58.80±1.281	14.57± .128	.798± .0094	158,600±2,576	680,000± 9,750	.6287± .0074
517	6.90± .229	74.30±1.403	15.94± .155	.748± .0096	166,700±2,536	630,300± 7,040	.7645± .0105
524	6.30± .243	71.43±1.227	15.70± .133	.741± .0070	165,900±2,443	642,600± 9,380	.8559± .0100
528	7.32± .283	79.60±1.619	17.28± .155	.769± .0088	146,200±2,406	521,800± 9,530	.5713± .0106
529	6.02± .236	63.25±1.349	15.46± .175	.798± .0114	169,300±2,684	649,100±13,230	.7275± .0091
541	8.09± .324	54.50± .944	12.49± .094	.913± .0108	197,500±2,555	830,000± 9,54	.7547± .0099
552	7.36± .276	61.70±1.214	15.07± .116	.704± .0073	153,300±2,554	724,800±11,270	.5969± .0095
553	7.80± .283	50.40±1.012	12.98± .140	.869± .0108	170,300±2,424	804,900±12,840	.7208± .0112
556	8.01± .263	77.00±1.158	16.08± .125	.694± .0067	170,300±2,254	653,000± 7,140	.7673± .0107
Averages (10)	7.33± .087	67.37± .407	15.19± .043	.769± .0029	167,000± 804	679,500± 3,170	.7164± .0032

[1] 530 omitted from the averages. Her wool was strictly one-half blood.

TABLE 2.—*Tensile strength and elasticity of wool from yearling wethers and ewes, 1917*—Continued

YEARLING RANGE WETHERS

Sheep No.	Stretch	Break	Diameter	Average elongation	Tensile strength	Young's modulus	Elastic limit on equal area
	Mm.	*Dgm.*	μ				
561	6.22±0.206	52.30±1.214	13.03±0.135	0.858±0.0148	179,900±2,923	850,900±16,400	0.9442±0.0145
565	4.98± .142	49.10± .668	12.92± .121	.938± .0141	170,800±2,673	780,000±13,610	.8267± .0131
569	7.00± .162	53.00± .853	13.30± .137	.900± .0099	175,000±3,274	751,000±14,530	.7853± .0151
Averages	6.07± .0991	51.47± .542	13.08± .076	.899± .0076	175,200±1,713	794,000± 8,600	.8521± .0082

YEARLING RANGE EWE

562	7.00±0.216	53.30±0.809	13.51±0.108	1.153±0.0148	168,200±2,945	565,800±7,840	0.8589±0.0098
Averages (4)	6.30± .092	51.92± .454	13.19± .063	.962± .0068	173,500±1,481	736,900±6,740	.8538± .0066

TABLE 3.—*Tensile strength and elasticity of wool from aged ewes, 1918*

LOT 1

(EWES GRAZED ON IRRIGATED FENCED PASTURE; GOOD FEED IN WINTER; SHELTER)

Sheep No.	Stretch	Break	Diameter	Average elongation	Tensile strength	Young's modulus	Elastic limit on equal area
	Mm.	*Dgm.*	μ				
529	6.92±0.189	55.36±1.012	14.64±0.121	1.012±0.0148	128,700±1,963	562,400± 8,090	0.6582±0.0108
530 [1]	8.52± .256	104.24±2.226	19.53± .209	.546± .0094	153,900±2,159	596,800±12,230	.7397± .0132
541	8.54± .249	42.40± .742	12.08± .121	1.213± .0256	168,400±3,105	775,700±16,860	.8504± .0170
578	9.81± .236	45.15±1.012	12.78± .148	1.362± .0290	159,700±3,100	576,500±11,060	.7419± .0146
221–572	10.82± .249	73.94±1.583	15.68± .142	.884± .0135	177,200±3,283	557,900±11,120	.8615± .0174
392–696	9.02± .216	58.03±1.079	15.00± .142	.988± .0121	150,900±3,195	563,800±12,190	.7488± .0193
393–961	8.67± .256	50.26± .809	14.07± .121	.990± .0168	148,100±2,966	625,800±13,350	.7371± .0130
406–980	7.04± .256	40.39± .877	12.78± .128	1.233± .0283	141,800±3,197	635,800±14,110	.7843± .0146
407–959	9.16± .297	51.79±1.281	13.47± .169	1.153± .0229	160,300±1,966	590,200±11,110	.7929± .0095
508–678	8.53± .196	52.29± .877	13.44± .121	.940± .0155	166,100±2,666	736,800±16,580	.7820± .0120
655–656	9.72± .236	54.76± .944	13.89± .135	.938± .0215	163,100±3,130	695,900±16,590	.7847± .0152
Averages (10)	8.82± .076	52.44± .332	13.78± .043	1.070± .0066	156,400± 916	632,100± 4,240	.7742± .0046

LOT 2

(SEMIRANGE EWES)

517	9.12±0.222	62.19±1.147	15.94±0.167	0.925±0.0134	158,600±2,495	578,700±12,180	0.7693±0.0206
552	7.70± .182	55.76±1.279	14.09± .142	.850± .0148	168,000±2,482	725,200±14,550	.7461± .0125
80–463	9.90± .206	45.70± .526	12.08± .088	1.154± .0182	181,200±2,759	723,200±14,310	.8635± .0140
399–690	8.68± .202	46.76± .722	13.23± .135	1.244± .0202	155,700±3,073	566,300±10,790	.7836± .0136
401–489	8.81± .209	50.21± .944	13.86± .135	1.027± .0162	151,000±2,475	615,300± 9,990	.7360± .0101
476–477	7.30± .179	42.02± .742	13.40± .142	1.121± .0259	139,000±2,547	646,000±14,290	.7059± .0135
Averages (6)	8.58± .082	50.44± .380	13.77± .056	1.053± .0076	158,900±1,081	642,400± 5,230	.7674± .0059

[1] 530 omitted from mean because of coarse fiber. This ewe produced half-blood wool.

The results of these tests are given in Tables 1, 2, and 3. Stretch represents total stretch at the breaking point. Break is the stress at the breaking point in decigrams. Diameters are expressed in

microns. Average elongation is the average stretch produced by the successive increments of 5 dgm. of stress. Tensile strength = $\frac{\text{Breaking stress in decigrams}}{\text{Area of cross section in square millimeters.}}$ Young's modulus = $\frac{L \times S}{E \times A}$. The length of fiber under test (L) is expressed in millimeters; stress (S), expressed in grams, refers to the increments of 0.5 gm. added at regular intervals: Average stretch or elongation (E), expressed in units of 2 mm., refers to the average stretch produced by the increments of 0.5 gm. before the elastic limit point is reached. Elastic limit on equal area = $\frac{\text{Elastic limit point in decigrams.}}{\text{Area of cross section in sq. mm.}}$

All samples tested in these studies were taken from the middle of the shoulder.

Average results indicate lower values for range ewes for stretch, break, and diameter, and higher values for range ewes for average elongation, tensile strength, Young's modulus, and elastic limit on equal area. Although the individual results are not consistent, the probable errors of some of the averages are small enough in proportion to the differences between averages to make the results seem significant.

Similar but more widely differing results were obtained with yearlings in 1917 as indicated in Table 2. In 1918 the results with aged ewes agreed only in part with those obtained with similar ewes in 1917.

Composite graphs representing diameter and elastic limit on equal area are given in Figures 1 and 2. The graphs representing elastic limit on equal area are considered typical also of those representing tensile strength and Young's modulus. The latter are therefore not included in this paper.

Considering the composite graphs, a rather uniform tendency is noted toward a smaller diameter of fiber from the aged ewes as well as from the yearling wethers and the yearling ewe kept under range or semirange conditions as contrasted with the corresponding measurements from ewes kept under more favorable conditions as to feed, shelter, and general care. The data on tensile strength, Young's modulus, and elastic limit on equal area are not definite in their significance since the differences in the results obtained on aged ewes in 1918 are but little more than the probable errors of the means.

The greater strength of the smaller fibers per unit of area of cross section is explainable on the basis of the structure, the medulla obviously contributing less strength than the cortex in proportion to the areas of their respective cross sections. This relation in structure accounts for the fact that the tensile strength, Young's modului, and the elastic limits on equal area are not proportional to the diameter. These quantities are functions of the respective areas of cross section of the cortex and medulla and of their respective strength, rather than of the total area of the cross section of the fiber or of the diameter of the fiber.

No data were available to indicate the basis of selection of the ewes placed on the range in 1916, and it was therefore not established that these ewes were closely comparable with those kept in the home flock. In other words, the effect of feed and other external conditions on the diameter of wool fibers could not be determined from the data for these ewes. It seems, however, that the strength and

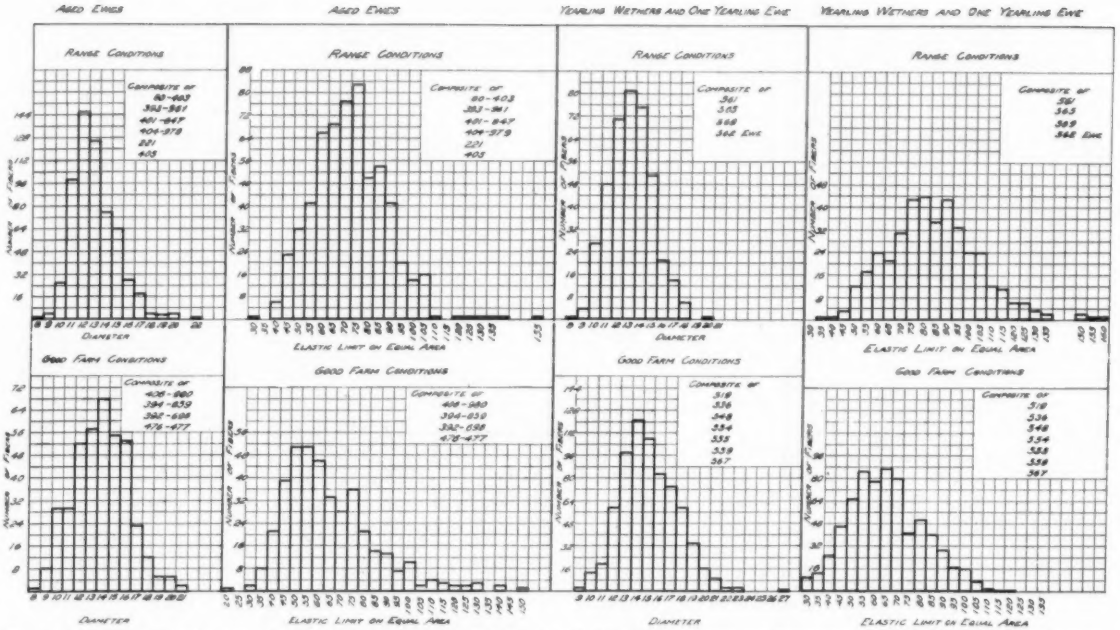

FIG. 1.—Composite graphs showing diameters and elastic limit on equal area of wool fibers from aged ewes, yearling wethers, and yearling ewe kept under range conditions and under good farm conditions in 1917

elasticity as related to the diameter of the fibers were somewhat similar among the individuals in the two lots.

It seemed desirable to obtain a more accurate check on individuality and to reduce the number of variable factors in the experiment. Wethers were therefore selected for further study with the idea of eliminating such factors as oestrum, pregnancy, lambing, and milk production, and with the further idea of using these animals as subjects through a sufficient period of years to determine the effect of different rations on a series of fleeces produced by the same wether. In this way a check was obtained on the individuality of the wether.

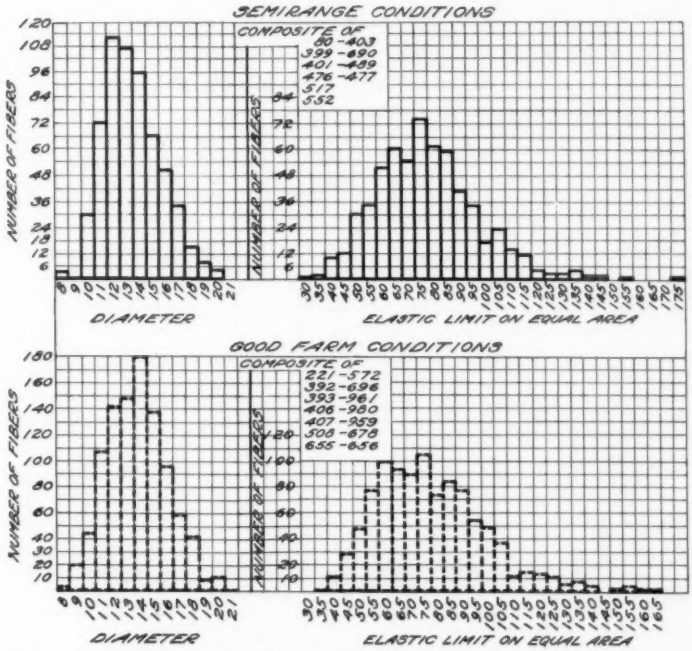

FIG. 2.—Composite graphs showing diameters and elastic limit on equal area of wool fibers from aged ewes kept under semirange conditions and under good farm conditions in 1918

The feeding period ranged from five to six months each year. During the remainder of the year the wethers were run together.

During the first year of the test one lot of wethers was fed an average daily ration of 4 pounds of alfalfa hay and 0.6 pound of a mixture of oats 3 parts and oil meal 1 part. The second lot was fed 4 pounds of mixed hay consisting of timothy 3 parts to medium red clover 1 part.

In 1920 and 1921 one lot was fed an average daily ration of 4 pounds of alfalfa of good quality. The other lot was fed oat straw which contained no grain and a very limited quantity of chaff and 4 ounces per head of cottonseed cake containing 43 per cent protein.

The results of the tests of wool fibers are given in Tables 4, 5, and 6 and in Figures 3, 4, 5, 6, and 7.

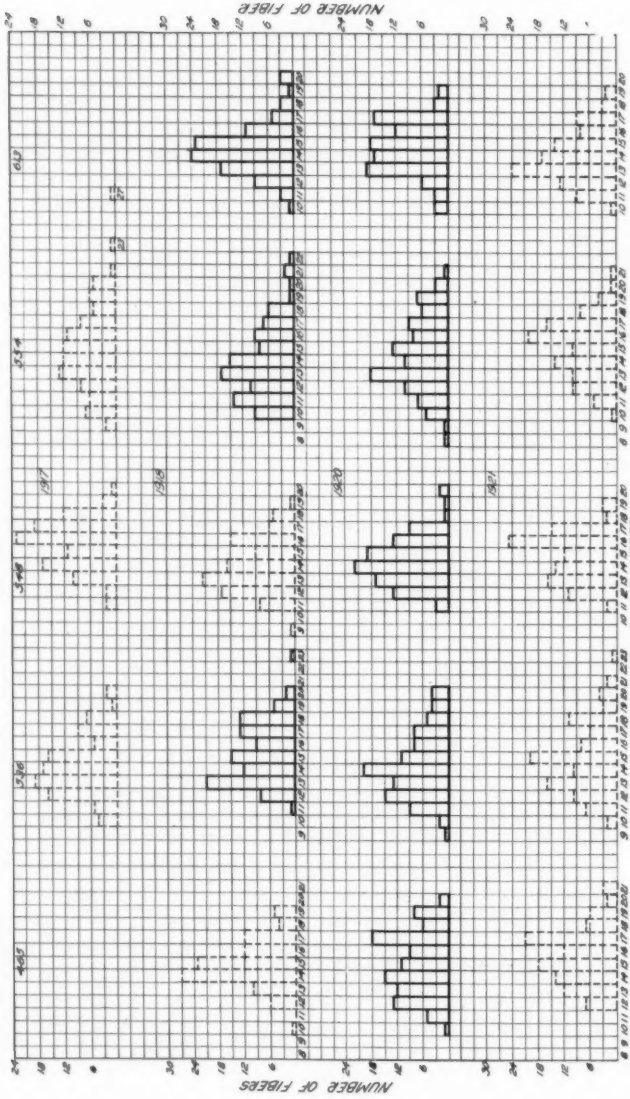

FIG. 3.—Diameters of wool fibers from wethers ranging in age from 1 to 5 years. Broken lines, liberal feed; solid lines, limited feed

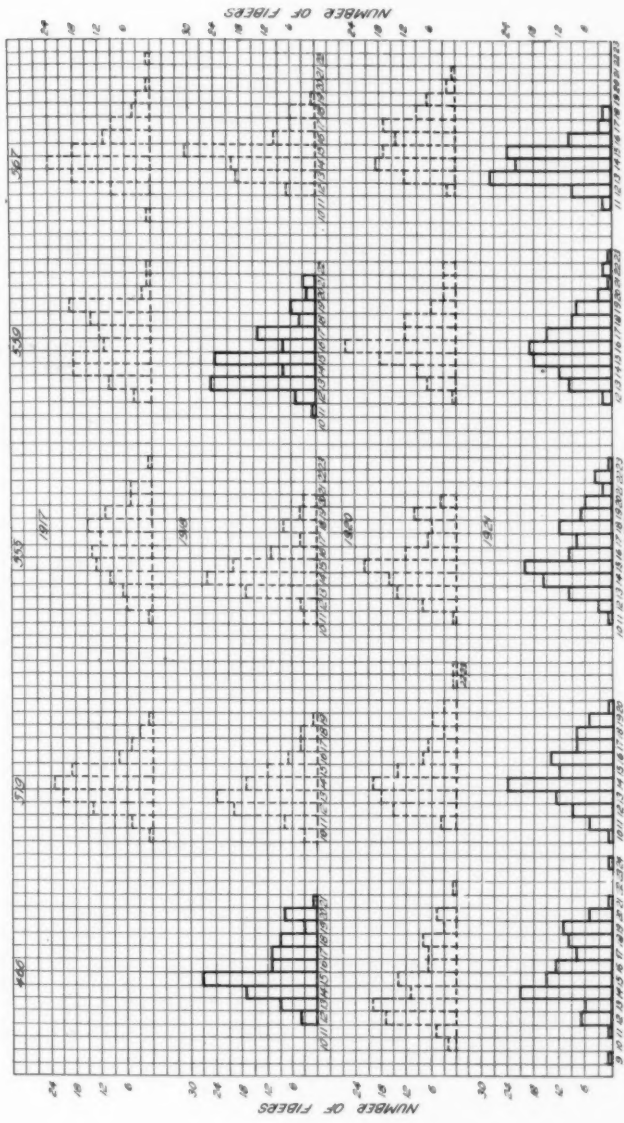

FIG. 4.—Diameters of wool fibers from wethers ranging in age from 1 to 5 years. Broken lines, liberal feed; solid lines, limited feed.

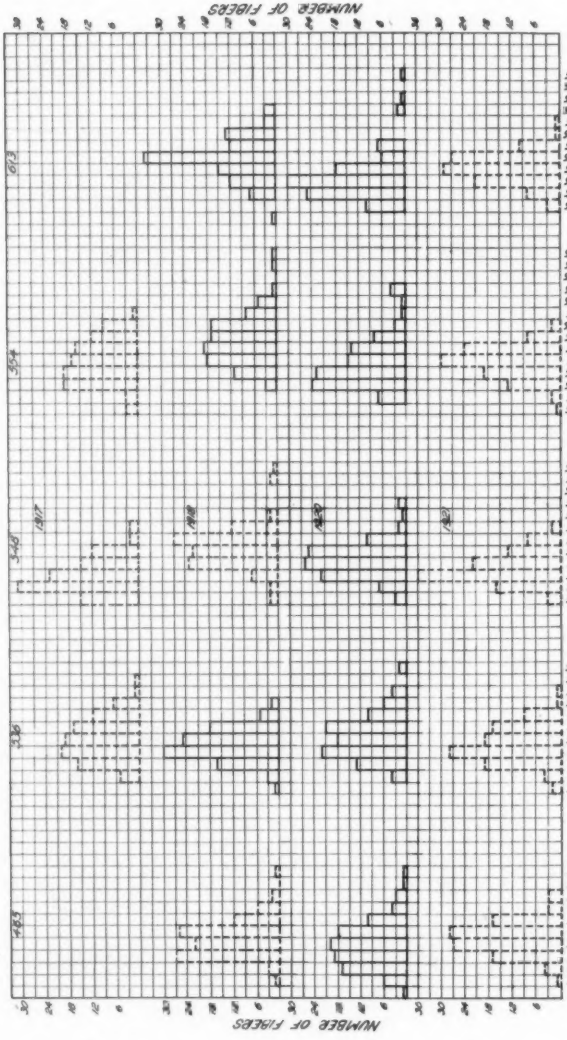

FIG. 5.—Elastic limit on equal area of wool fibers from wethers ranging in age from 1 to 5 years. Broken lines, liberal feed; solid lines, limited feed

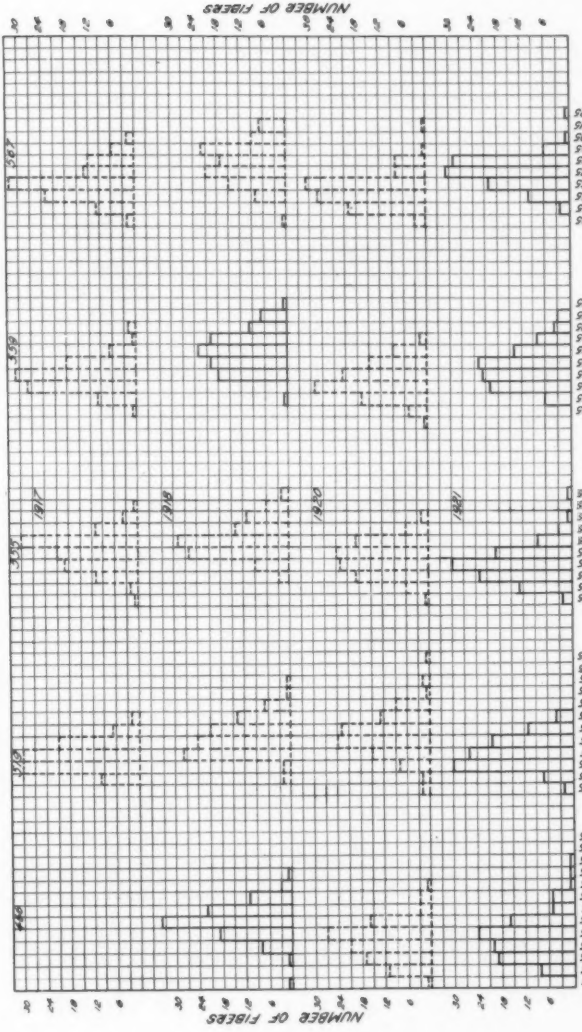

FIG. 6.—Elastic limit on equal area of wool fibers from wethers ranging in age from 1 to 5 years. Broken lines, liberal feed; solid lines, limited feed

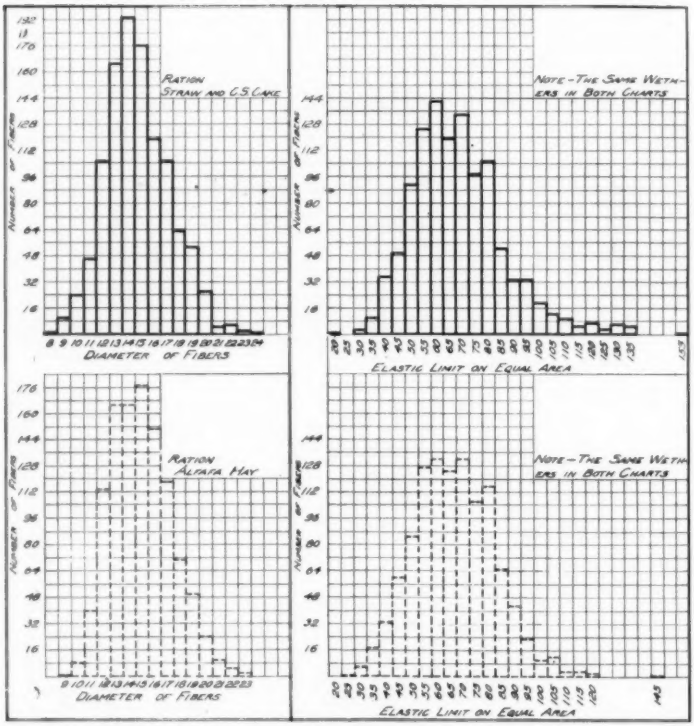

FIG. 7.—Diameters and elastic limit on equal area of wool fibers from 11 wethers, 1920 and 1921. One group of these wethers was fed straw and cottonseed cake during the winter of 1920 and alfalfa hay during the winter of 1921. The other group was fed these rations in the reverse order during the respective years. The same wethers are represented in all graphs, thus eliminating the variation which would result from the use of different sets of individuals in the two lots. Solid lines indicate limited feed, broken lines, liberal feed

The graphs in this figure are composites of those in Figures 3, 4, 5, and 6 for the years 1920 and 1921, in which each wether was represented by a separate graph. By eliminating variation due to testing limited numbers of fibers from each sample, great uniformity of results is obtained even though the rations differed markedly in feeding value

TABLE 4.—*Tensile strength and elasticity of wool, 1918*

LOT 1

(RAMBOUILLET WETHERS; RATION DURING THE WINTER FEEDING PERIOD, ALFALFA HAY, OATS, AND LINSEED-OIL MEAL)

Sheep No.	Stretch	Break	Diameter	Average elongation	Tensile strength	Young's modulus	Elastic limit on equal area
	mm.	*Dgm.*	μ				
465	10.24±0.243	59.34±1.214	15.10±0.115	1.161±0.0269	146,400±2,219	545,200±9,370	0.6751±0.0099
519	8.43± .229	50.74±1.214	13.61± .128	1.239± .0209	153,100±1,965	529,800±7.550	.7614± .0098
548	8.35± .236	49.89± .944	14.06± .135	1.126± .0188	144,300±2,041	555,500±11,010	.7344± .0118
555	7.52± .216	57.06±1.012	14.95± .135	.925± .0115	145,100±2,118	574,000±8,240	.8347± .0112
567	8.67± .236	58.25±1.079	14.65± .101	.999± .0134	152,900±2,119	553,800±6,840	.8064± .0112
Averages	8.64± .104	55.06± .491	14.47± .055	1.090± .0085	148,360±936	551,700±3,900	.7624± .0048

LOT 2

(RAMBOUILLET WETHERS; RATION DURING THE WINTER FEEDING PERIOD, MIXED HAY, I. E., TIMOTHY AND CLOVER)

466	9.05±0.229	69.66±1.416	15.71±0.142	0.858±0.0114	158,600±1,896	563,300±6,480	0.8424±0.0094
536	8.22± .229	57.31±1.416	15.38± .155	1.008± .0195	136,400±2,085	520,600±8,530	.6816± .0086
554	7.65± .209	55.25±1.281	13.92± .182	1.028± .0203	161,800±2,532	643,400±12,830	.8904± .0137
559	9.04± .256	63.29±1.281	15.24± .155	.911± .0121	154,100±2,196	571,200±8,780	.8265± .0102
613	10.15± .217	61.20±1.179	14.48± .121	.918± .0141	173,900±2,460	610,500±9,660	.8201± .0107
Averages	8.82± .102	61.34± .589	14.95± .068	.945± .0071	157,000±1,005	581,800±4,240	.8122± .0048

TABLE 5.—*Tensile strength and elasticity of wool, 1920*

LOT 1

(RAMBOUILLET WETHERS; RATION DURING THE WINTER FEEDING PERIOD, ALFALFA HAY)

Sheep No.	Stretch	Break	Diameter	Average elongation	Tensile strength	Young's modulus	Elastic limit on equal area
	mm.	*Dgm.*	μ				
466	5.62±0.276	57.32±1.281	14.63±0.179	1.081±0.0162	148,460±2,191	581,100±8,350	0.6694±0.01018
519	8.89± .263	59.94±1.214	14.72± .169	1.134± .0135	159,160±2,343	562,300±9,510	.7795± .01254
555	7.10± .297	60.66±1.214	15.45± .148	.864± .0115	146,440±2,144	585,100±8,040	.6771± .00951
559	6.27± .275	72.56±1.375	16.37± .142	.900± .0084	149,880±2,207	493,700±7,060	.5807± .00910
567	10.23± .303	66.14±1.012	15.73± .128	1.001± .0141	156,390±2,361	474,200±12,710	.5851± .00910
Average	7.62± .127	63.32± .548	15.38± .069	.996± .0058	152,070±1,007	539,300±4,220	.6583± .0046

LOT 2

(RAMBOUILLET WETHERS; RATION DURING THE WINTER FEEDING PERIOD, STRAW AND COTTONSEED CAKE)

465	6.78±0.238	55.59±1.099	15.06±0.167	1.129±0.0169	145,260±3,048	495,000±12,080	0.6209±0.01194
492	9.04± .270	49.17± .850	13.35± .144	1.320± .0164	176,190±2,816	569,400±10,420	.7704± .01389
536	8.07± .249	59.68±1.214	14.33± .169	.894± .0135	165,310±2,738	650,100±11,000	.7520± .01268
548	7.35± .256	59.21±1.402	14.79± .126	1.012± .0157	157,800±2,553	596,000±7,240	.6482± .01031
554	8.98± .297	60.53±1.584	14.29± .189	.988± .0209	161,300±2,560	597,300±10,870	.7002± .01409
613	6.22± .290	58.95±1.160	14.73± .133	1.013± .0209	155,630±3,409	557,700±11,190	.6617± .01240
Average	7.74± .109	57.19± .506	14.42± .064	1.059± .0072	160,200±1,171	572,600±4,320	.6939± .00515

TABLE 6.—*Tensile strength and elasticity of wool, 1921*

LOT 1

(RAMBOUILLET WETHERS; RATION DURING THE WINTER FEEDING PERIOD, STRAW AND COTTONSEED CAKE)

Sheep No.	Stretch	Break	Diameter	Average elongation	Tensile strength	Young's modulus	Elastic limit on equal area
	mm.	*Dgm.*	*μ*				
466	9. 66±0. 283	70. 60±1. 821	15. 89±0. 175	1. 066±0. 0243	154, 860±2, 515	459, 600±7, 160	0. 6813±0. 0117
519	7. 94± . 229	52. 80±1. 079	14. 79± . 148	1. 464± . 0378	137, 280±1, 954	385, 800±5, 890	. 6316± . 0086
555	8. 86± . 256	65. 45±1. 686	16. 27± . 182	1. 152± . 0189	136, 820±2, 116	397, 500±5, 200	. 6173± . 0100
559	9. 20± . 268	69. 10±1. 420	16. 21± . 140	1. 028± . 0174	149, 420±1, 836	452, 900±7, 010	. 6906± . 0107
567	11. 10± . 310	63. 30±1. 079	14. 19± . 096	1. 148± . 0296	178, 120±2, 482	510, 100±6, 180	. 7235± . 0082
637 [1]	9. 66± . 242	54. 55±1. 360	13. 86± . 162	1. 316± . 0270	160, 120±2, 674	482, 500±7, 190	. 6459± . 0104
730 [2]	10. 14± . 310	57. 40±1. 110	14. 41± . 121	1. 320± . 0240	155, 170±2, 444	446, 100±6, 240	. 6710± . 0101
Average	9. 50± . 103	61. 89± . 527	15. 09± . 056	1. 212± . 0100	153, 110± 872	447, 800±2, 440	. 6659± . 0038

LOT 2

(RAMBOUILLET WETHERS; RATION DURING THE WINTER FEEDING PERIOD, ALFALFA HAY)

465	9. 94±0. 270	68. 05±1. 551	15. 79±0. 142	1. 178±0. 0187	153, 600±2, 335	411, 000±5, 710	0. 6766±0. 0087
492	12. 66± . 283	61. 38±1. 147	13. 74± . 115	1. 408± . 0311	168, 070±2, 599	471, 800±9, 650	. 6580± . 0105
536 [3]	9. 70± . 270	61. 75±1. 416	14. 90± . 182	1. 229± . 0214	158, 386±2, 935	447, 000±7, 360	. 6803± . 0100
548 [4]	9. 72± . 256	54. 55±1. 012	14. 93± . 128	1. 382± . 0322	141, 960±2, 031	395, 500±5, 770	. 5869± . 0085
554	11. 04± . 324	69. 15±1. 659	15. 05± . 155	1. 166± . 0243	167, 410±2, 457	447, 600±5, 780	. 7111± . 0088
613	11. 62± . 270	64. 04±1. 281	13. 92± . 128	1. 098± . 0202	182, 140±2, 191	554, 500±6, 770	. 7331± . 0088
759 [5]	9. 48± . 268	61. 15±1. 110	14. 26± . 137	1. 060± . 0140	171, 300±2, 298	556, 700±7, 920	. 6862± . 0100
Average	10. 59± . 105	62. 87± . 503	14. 66± . 054	1. 217± . 0090	163, 270± 915	469, 200±2, 690	. 6760± . 0035

[1] Fifteen fibers broke while being adjusted in the machine.
[2] One fiber broke while being adjusted in the machine.
[3] One fiber broke while being adjusted in the machine.
[4] Four fibers broke while being adjusted in the machine.
[5] Five fibers broke while being adjusted in the machine.

An analysis of the results therein shown, reveals no variation in stretch, break, diameter, average elongation, tensile strength, Young's modulus, or elastic limit on equal area which can be ascribed to differences in the feed during the test period. The small differences in results obtained on any individual from year to year appear to be due to errors in sampling and to variability of the limited numbers of fibers tested; in other words, to the normal experimental error. The charts showing the distribution of all fibers tested from a given group of wethers under different feed conditions show clearly how uniform the results were. Notwithstanding the rather wide variation in feed during the test period, the secretion of the wool fibers took place in a uniform manner in so far as size, strength, and elasticity of the fibers were concerned, and apparently the relations of the medulla and the cortex of the fibers remained the same under the two conditions.

The condition or degree of fatness of the wethers was clean cut at the end of the test-feeding period, those fed the more liberal ration uniformly carrying more fat. Those fed the limited rations during the last two years lost in weight, one wether actually losing at the rate of over one-third pound per day. Nor was there any question regarding the "condition" of the wool. The fleeces of the wethers in the lots fed straw and cottonseed cake were dry, harsh, and lifeless to the touch as compared to the fleeces of the wethers fed a liberal ration of alfalfa hay, which were in every case quite satisfactory in "condition."

The length of staple and weight of fleece were also considered in this connection. These are given in Table 7 in which they are arranged both chronologically without regard to the method of feeding and according to the method of feeding without regard to sequence in time.

TABLE 7.—*Weight of fleece and length of staple, 1920 and 1921*

ARRANGED CHRONOLOGICALLY

Wether No.	Weight of fleece in pounds		Length of staple in inches	
	1920	1921	1920	1921
465	12.8	14.6	2.34	2.17
466	13.2	11.1	2.69	2.40
492	10.9	11.7	2.81	2.72
519	14.6	12.7	2.37	2.27
536	12.9	13.2	2.98	2.71
548	13.0	14.1	2.10	2.16
554	13.7	15.8	2.76	2.63
555	16.6	12.5	3.04	2.47
559	14.6	12.4	3.36	2.98
567	18.2	16.1	2.76	2.55
613	[1] 12.7	[2] 13.9	[1] 2.70	[2] 2.70

ARRANGED ACCORDING TO RATION FED

Wether No.	Hay	Straw and cake	Hay	Straw and cake
465	14.6	12.8	2.17	2.34
466	13.2	11.1	2.69	2.40
492	11.7	10.9	2.72	2.81
519	14.6	12.7	2.37	2.27
536	13.2	12.9	2.71	2.98
548	14.1	13.0	2.16	2.10
554	15.8	13.7	2.63	2.76
555	16.6	12.5	3.04	2.47
559	14.6	12.4	3.36	2.98
567	18.2	16.1	2.76	2.55
613	13.9	12.7	2.70	2.70

[1] Second fleece. [2] Third fleece.

Arranged chronologically, the weights of the fleeces show complete absence of uniformity in tendency, but arranged according to the ration fed, the fleeces grown during the period in part of which hay was fed were uniformly heavier than those produced during the year represented by the test period on straw and cake.

With two exceptions the length of staple shows a uniform tendency to decrease with the advancing age of the wethers. One of these exceptions was that of number 613 which was 2 and 3 years old during the respective years of the test, whereas the other wethers were 3 and 4 or 4 and 5 years old during the same period. The second exception was that of a wether which was fed straw and cake during a part of the first year and hay during a part of the second year of the test. There is no tendency toward a decrease in length of staple in the third fleece as compared with the second fleece as is indicated by unpublished data.

Considering the data on length of staple as arranged in the second part of the table, there is complete lack of uniformity in tendency. Interpreting the two parts of the table, age is a greater factor in

determining length of staple than rather marked differences in the level of feeding continued over a period of five to six months. In other words, the length of staple will be modified almost imperceptibly by the level of feeding during the average feeding period on the ranges in Montana unless extreme differences are considered. The rate of secretion of the wool fiber during a short feeding period in winter, while subject to influence by feeding, is modified significantly only with some difficulty and under rather extreme conditions. Careful analysis of the data reveals a slight difference between the lots which is probably due to a more rapid decrease in length of staple if the ration of hay was fed the first year and straw and cake the second year, than if the rations were fed in the reverse order. In other words, while the feed as tested in this experiment seemed to influence the length of staple, this influence was purely secondary to that of age and therefore not capable of exact measurement with limited numbers of sheep.

There are opposed tendencies in length of staple and weight of fleece in this case, and there is no change in diameter of fiber or apparently in the quantitative relations of such structural parts of the fiber as influence its strength or elasticity. This is interpreted as indicating that while the physical properties of the wool fiber itself are not easily changed either quantitatively or qualitatively, the "yolk" or "grease" and other factors that go to make up shrinkage are easily subject to influence by the level of feeding even during a comparatively short period.

A very interesting case observed during this trial was that of wether No. 555 whose weight decreased over one-third of a pound per day during the feeding period of 174 days in 1921. The weight of his fleece decreased 4.1 pounds and the length of staple decreased 0.57 inch, but the diameter and the strength and elasticity of the wool fibers from his fleece were not influenced perceptibly by the level of feeding, notwithstanding the fact that he was so poorly nourished that he succumbed to an invasion of pus organisms even after he had been on pasture for some time following shearing and the close of the test period.

SUMMARY

The results of the investigation here reported indicate that in sheep of fine-wool breeding, the organs which are concerned with the secretion of the wool fiber are not easily subject to such influences as changes in the level of feeding, especially for periods of five to six months, if the sheep remain normal in health; that the quality of the wool fiber is affected not at all, and that the quantity of fiber may be modified only slightly, as long as the sheep remain in normal health; that age of wethers up to 5 years affects the diameter of wool fibers very slightly if at all; that advancing age after the third or fourth year causes a decrease in length of staple; that failures in selection of sheep for the production of adequate length of staple or amount of actual clean wool can not be compensated by better feeding during a short period in winter; that the level of winter feeding of sheep should be determined on the basis of the needs for other purposes such as creating or maintaining strength and condition for withstanding the rigors of winter, growth of body rather than of wool, production of strong lambs and of ample flow of milk at lambing

and after lambing; that if these points are properly observed the growth of wool will be provided for on a basis commensurate with its importance in the particular case; that any additional weight of fleece produced by more liberal feeding in winter consists of the factors making up shrinkage very largely and of actual wool fibers only slightly.

Although the fleeces produced during the years in which the wethers were fed at the lower levels lacked in "condition," it is still a question whether the spinning quality of the wool after scouring would be affected thereby; also, if adversely affected, whether the apparent lack of natural oily secretions could be compensated by the artificial application of oil.

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24880—26——7

A STRAIN OF YELLOW JERSEY SWEET POTATO RESISTANT TO SURFACE ROT (FUSARIUM OXYSPORUM W. & C.)[1]

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The loss of sweet potatoes in storage caused by surface rot is often large, especially in the Jersey varieties.[2, 3] Harter and Weimer [2] have reported losses as great as 25 per cent. Data are available (Table 1) which show that as high as 38 per cent of Yellow Jersey roots have become infected with surface rot under certain storage conditions.

TABLE 1.—*Resistance to surface rot of the selected strain of Yellow Jersey sweet potatoes as compared with the unselected stock*

Seed from which roots were taken	Number of crates used	Number of roots used	Number of roots infected	Percentage infected
Selected	6	777	50	0.6
Unselected	4	609	233	38.0

While examining Yellow Jersey roots in storage in 1923 and 1924 the writer observed that two types were present, one of which was free from surface rot. These roots were distinguished from the others, not only by the absence of the disease but by other characters. The two strains may be described as follows: The resistant strain is fusiform in shape, dark russet in color, and the skin has a tendency to crack at the root end. The cracking is very slight and does not affect the value of the strain. In some roots it is entirely absent. The susceptible strain is globose and light russet. The coloring is really dependent upon or correlated with the degree of russeting, with some variation in both strains. The difference is sufficiently marked to distinguish the two strains readily.

The origin of the strains is not known. There has been no opportunity for the roots used by the writer to become mixed since they came into his possession. Probably the strains had their origin at an earlier date, for they have been observed in commercial stocks. It is possible that they may have come from seed in their original home in the tropics, and always have been mixed since they were brought to this country, or they may have arisen from bud variations here. Harter [4] discovered three red roots and three yellow roots growing from the same vine of the Haiti variety of sweet potato in the fall of 1923. These two strains have reproduced true to type each season since.

[1] Received for publication July 26, 1926; issued December, 1926.

[2] HARTER, L. L., and WEIMER, J. L. THE SURFACE ROT OF SWEET POTATOES. Phytopathology 9: 465–469, illus. 1919.

[3] POOL, R. F. SWEET POTATO DISEASES IN NEW JERSEY. N. J. Agr. Expt. Sta. Circ. 141, 31 p., illus. 1922.

[4] HARTER, L. L. BUD SPORTS IN SWEET POTATO. Jour. Agr. Research 33: 523–525, illus. 1926.

A small number of roots resistant to surface rot were selected in the spring of 1924 and a planting was made from them along with a planting from unselected roots. The vines from the two plantings could not be distinguished from each other. The roots, however, reproduced true to type.

The plants from the resistant roots yielded 6 bushels of potatoes. These were stored in crates on October 10 in the same room and under the same conditions as those from the unselected seed (cured for 10 days at a temperature ranging from 21° to 24° C., stored at a temperature ranging from 10° to 15° and a relative humidity ranging from 55 to 75 per cent).

An inspection was made on March 11, the following spring, of all the selected stock and four crates of the unselected. The results are recorded in Table 1. The roots of the resistant strain showed only three-fifths of 1 per cent infection, whereas those from the unselected seed showed 38 per cent. This contrast becomes more striking when it is considered that there were many roots of the resistant strain mixed with those of the unselected stock.

In order to compare the resistant strain more directly with the susceptible, a selection of the latter was made in the spring of 1925, and a planting made from the two. Both reproduced true to type.

Sixty crates of the resistant and 48 of the susceptible strain were divided into four equal lots in each case and one lot of each strain was cured for 10 days under each of four different conditions of curing: (1) Temperature 21° to 24° C., relative humidity 70 to 80 per cent; (2) temperature 24° to 27°, relative humidity 45 to 60 per cent; (3) temperature 27° to 29°, relative humidity 45 to 55 per cent; and (4) temperature 29° to 32°, relative humidity 40 to 50 per cent. The potatoes of each strain under each curing condition were then subdivided into four equal lots, one of which was stored at each of four different humidities (62 to 68, 73 to 76, 77 to 84, and 81 to 87 per cent), the temperature being practically the same in each case. Each strain was thus subjected to 16 different combinations of conditions as to curing and storage humidity. The storage period extended from October 16, 1925, to March 10, 1926.

The results are summarized in Tables 2 and 3 in such a way that one can compare directly the effect on the development of surface rot of curing on the one hand and of humidity of storage on the other. The total number of infections under all conditions is also given.

The variation in the percentage of infection of the resistant strain under the conditions given in the tables ranged from 3 to 13, that of the susceptible from 35 to 57. The highest percentage of infection in the resistant strain obtained under any of the 16 combinations of conditions to which the roots were exposed was 21 (curing temperature 29° to 32° C., relative humidity 62 to 68 per cent). The percentage of infection of the susceptible strain under the same conditions was 55. The highest percentage of infection of the susceptible strain was 64 (curing temperature, 29° to 32°, relative humidity 77 to 84 per cent). The percentage of infection of the resistant strain under the same conditions was 6. The lowest percentage of infection obtained with the resistant strain was 1 (potatoes cured at 21° to 24° and stored at relative humidities of 81 to 87 per cent and potatoes cured at 24° to 27° and stored at relative humidities of 81 to 87 per cent). The percentage of infection of the susceptible

TABLE 2.—*Resistance to surface rot of the susceptible and resistant strains of yellow Jersey sweet potato under different conditions of curing*[a]

Curing temperature, °C.	Curing relative humidity, per cent	Storage temperature, °C.	Storage relative humidity	Resistant strain			Susceptible strain		
				Number of roots used	Number infected	Percentage infected	Number of roots used	Number infected	Percentage infected
21 to 24	70 to 80	10 to 15 throughout storage period	The data recorded at each of the curing temperatures and humidities were obtained from potatoes stored at each of the storage humidities recorded in Table 3.	2,685	167	6	1,528	616	40
24 to 27	45 to 60			2,191	79	4	1,509	529	35
27 to 29	45 to 55			2,110	191	9	1,520	624	41
29 to 32	40 to 50			2,199	230	10	1,495	845	57
Total				9,185	667	7	6,052	2,614	43

[a] Duration of curing and storage periods, 10 and 127 days, respectively.

TABLE 3.—*Resistance to surface rot of the susceptible and resistant strains of yellow Jersey sweet potato under different storage humidities*[a]

Storage relative humidity, per cent	Storage temperature, °C.	Curing temperature and relative humidity	Resistant strain			Susceptible strain		
			Number of roots used	Number infected	Percentage infected	Number of roots used	Number infected	Percentage infected
81 to 87	10 to 15 throughout storage period	The data recorded at each storage humidity were obtained from potatoes cured at each of the curing temperatures and humidities recorded in Table 2.	2,274	60	3	1,397	515	37
77 to 84			2,642	192	7	1,469	556	38
73 to 76			2,562	194	8	1,594	740	46
62 to 68			1,707	221	13	1,592	803	50
total			9,185	667	7	6,052	2,614	43

[a] Duration of curing and storage periods, 10 and 127 days, respectively.

strain under the same conditions was 44 and 28, respectively. The lowest percentage of infection of the susceptible strain was 24 (curing temperature 24° to 27° and relative humidity 77 to 84 per cent and at curing temperature 27° to 29° and relative humidity 81 to 87). The percentage of infection of the resistant strain under the same conditions was 3 and 5, respectively. The total percentage of infection of the resistant strain under all conditions was 7, while that of the susceptible was 43.

It is not the purpose of this paper to discuss curing and humidity as factors in the development of surface rot, but merely to show that the resistant strain exhibits a marked resistance under a variety of conditions, conditions that are evidently favorable to surface rot.

The results here reported show that the dark strain (resistant strain) is markedly resistant to surface rot, although it is not entirely immune. This resistance is further evidenced by the fact that the lesions in the resistant strain are fewer in number and shallower than in the susceptible. There is also a tendency in the susceptible strain for the roots to shrivel about the lesions, which is almost entirely absent in the resistant. This tendency to shrivel is not to be re-

A small number of roots resistant to surface rot were selected in the spring of 1924 and a planting was made from them along with a planting from unselected roots. The vines from the two plantings could not be distinguished from each other. The roots, however, reproduced true to type.

The plants from the resistant roots yielded 6 bushels of potatoes. These were stored in crates on October 10 in the same room and under the same conditions as those from the unselected seed (cured for 10 days at a temperature ranging from 21° to 24° C., stored at a temperature ranging from 10° to 15° and a relative humidity ranging from 55 to 75 per cent).

An inspection was made on March 11, the following spring, of all the selected stock and four crates of the unselected. The results are recorded in Table 1. The roots of the resistant strain showed only three-fifths of 1 per cent infection, whereas those from the unselected seed showed 38 per cent. This contrast becomes more striking when it is considered that there were many roots of the resistant strain mixed with those of the unselected stock.

In order to compare the resistant strain more directly with the susceptible, a selection of the latter was made in the spring of 1925, and a planting made from the two. Both reproduced true to type.

Sixty crates of the resistant and 48 of the susceptible strain were divided into four equal lots in each case and one lot of each strain was cured for 10 days under each of four different conditions of curing: (1) Temperature 21° to 24° C., relative humidity 70 to 80 per cent; (2) temperature 24° to 27°, relative humidity 45 to 60 per cent; (3) temperature 27° to 29°, relative humidity 45 to 55 per cent; and (4) temperature 29° to 32°, relative humidity 40 to 50 per cent. The potatoes of each strain under each curing condition were then subdivided into four equal lots, one of which was stored at each of four different humidities (62 to 68, 73 to 76, 77 to 84, and 81 to 87 per cent), the temperature being practically the same in each case. Each strain was thus subjected to 16 different combinations of conditions as to curing and storage humidity. The storage period extended from October 16, 1925, to March 10, 1926.

The results are summarized in Tables 2 and 3 in such a way that one can compare directly the effect on the development of surface rot of curing on the one hand and of humidity of storage on the other. The total number of infections under all conditions is also given.

The variation in the percentage of infection of the resistant strain under the conditions given in the tables ranged from 3 to 13, that of the susceptible from 35 to 57. The highest percentage of infection in the resistant strain obtained under any of the 16 combinations of conditions to which the roots were exposed was 21 (curing temperature 29° to 32° C., relative humidity 62 to 68 per cent). The percentage of infection of the susceptible strain under the same conditions was 55. The highest percentage of infection of the susceptible strain was 64 (curing temperature, 29° to 32°, relative humidity 77 to 84 per cent). The percentage of infection of the resistant strain under the same conditions was 6. The lowest percentage of infection obtained with the resistant strain was 1 (potatoes cured at 21° to 24° and stored at relative humidities of 81 to 87 per cent and potatoes cured at 24° to 27° and stored at relative humidities of 81 to 87 per cent). The percentage of infection of the susceptible

TABLE 2.—*Resistance to surface rot of the susceptible and resistant strains of yellow Jersey sweet potato under different conditions of curing*[a]

Curing temperature, °C.	Curing relative humidity, per cent	Storage temperature, °C.	Storage relative humidity	Resistant strain			Susceptible strain		
				Number of roots used	Number infected	Percentage infected	Number of roots used	Number infected	Percentage infected
21 to 24	70 to 80	10 to 15 throughout storage period	The data recorded at each of the curing temperatures and humidities were obtained from potatoes stored at each of the storage humidities recorded in Table 3.	2,685	167	6	1,528	616	40
24 to 27	45 to 60			2,191	79	4	1,509	529	35
27 to 29	45 to 55			2,110	191	9	1,520	624	41
29 to 32	40 to 50			2,199	230	10	1,495	845	57
Total				9,185	667	7	6,052	2,614	43

[a] Duration of curing and storage periods, 10 and 127 days, respectively.

TABLE 3.—*Resistance to surface rot of the susceptible and resistant strains of yellow Jersey sweet potato under different storage humidities*[a]

Storage relative humidity, per cent	Storage temperature, °C.	Curing temperature and relative humidity	Resistant strain			Susceptible strain		
			Number of roots used	Number infected	Percentage infected	Number of roots used	Number infected	Percentage infected
81 to 87	10 to 15 throughout storage period	The data recorded at each storage humidity were obtained from potatoes cured at each of the curing temperatures and humidities recorded in Table 2.	2,274	60	3	1,397	515	37
77 to 84			2,642	192	7	1,469	556	38
73 to 76			2,562	194	8	1,594	740	46
62 to 68			1,707	221	13	1,502	803	50
total			9,185	667	7	6,052	2,614	43

[a] Duration of curing and storage periods, 10 and 127 days, respectively.

strain under the same conditions was 44 and 28, respectively. The lowest percentage of infection of the susceptible strain was 24 (curing temperature 24° to 27° and relative humidity 77 to 84 per cent and at curing temperature 27° to 29° and relative humidity 81 to 87). The percentage of infection of the resistant strain under the same conditions was 3 and 5, respectively. The total percentage of infection of the resistant strain under all conditions was 7, while that of the susceptible was 43.

It is not the purpose of this paper to discuss curing and humidity as factors in the development of surface rot, but merely to show that the resistant strain exhibits a marked resistance under a variety of conditions, conditions that are evidently favorable to surface rot.

The results here reported show that the dark strain (resistant strain) is markedly resistant to surface rot, although it is not entirely immune. This resistance is further evidenced by the fact that the lesions in the resistant strain are fewer in number and shallower than in the susceptible. There is also a tendency in the susceptible strain for the roots to shrivel about the lesions, which is almost entirely absent in the resistant. This tendency to shrivel is not to be re-

garded as a result of disease, however, but rather as a characteristic of the susceptible strain, for the roots shrivel at the tip to a marked degree even when they are not infected with surface rot. The resistant strain, on the other hand, shows very little tendency to shrivel even under very dry conditions.

It is proposed to call the resistant strain Improved Yellow Jersey for the following reasons: (1) Because of its resistance to surface rot and (2) because it withstands shriveling to a marked degree.

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